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Long Range Planning in Technical Industries*

by MELVIN E. SALVESON

The Center for Advanced Management, Inc., New Canaan, Connecticut

Foreword: After this manuscript was submitted for publication, the writer encountered a report of the Company Planning Research Section of the Stanford Research Institute (News Front, July, 1959) on "What Makes Companies Grow." The findings of that study are so important to the manuscript that some of those findings are cited here.

One primary finding of the Stanford Research Institute is that "Long Range Planning is one of the most important growth factors. Both high growth companies that remained high in growth and low growth companies which increased their rate of growth devoted much more effort to planning than those companies whose rate of growth slowed down." The article which follows describes findings of the Center for Advanced Management on how successful long range planning is carried out and is applied by growth companies.

Another finding on mechanisms of growth is: "Expansion through large scale acquisition was characteristic of 55% of the high growth companies studied. Diversification, while highly valuable when properly planned, does not in itself guarantee a rise in rate of growth. Low growth companies, whose rate of growth failed to increase, actually diversified more than those whose rate of growth improved." This article also describes findings of the Center for Advanced Management on the criteria for effective expansion through acquisition and for effective diversification, as used by growth companies.

It is hoped, therefore, that the following article will be of especial importance and value to companies engaged in the high growth technical industries and to those who wish to enter these industries.

LONG range planning is becoming the sine qua non of every corporation which requires a continuing flow of profit for its survival and growth. The factors demanding increased LRP are many and impelling; the more important ones are summarized below. At the same time, the factors mitigating against effective LRP are many and impelling, and also are summarized below. Out of these countervailing forces, a broader view to LRP is suggested here. This view is concerned more with establishing the conditions for long range "all-weather" *viability* and *profit;* less with attempting to pinpoint specific plans, steps, and events in an amorphous, opaque future. Thus, long range planning, as defined here, is concerned with discovering and adapting total business operations to the strong patterns and trends which underlie progress and change in an industry or in the economy.

The trends which create the heaviest need for LRP are found in the technical industries. Thus, this report is oriented to those industries. In large part, it is based on studies performed by the Center For Advanced Management for an electro-mechanical and electronics manufacturer in a highly technical industry.

TECHNICAL INDUSTRY

A "technical" industry is defined broadly as one in which there is a high degree of scientific or technological knowledge required for performing its processes, for designing its product, or for managing its operations. Typical technical industries include petro-chemicals, electronic, aircraft and missile, pharmaceuticals, etc. An insistent problem in these industries requiring LRP is technological, or other, "change." However, the change is qualitatively different from "non-technical" industries, and this difference creates the heightened need for LRP. The women's garment industry illustrates the basic difference between change in the technical versus the non-technical industries. In that industry, for example, there is change from season-to-season, year-to-year, and period-to-period. A recent scientific study by psychologists indicated these changes are motivated largely by the value of avoiding boredom in the wearer's appeal or attractiveness. Thus, different portions of the anatomy are emphasized under successive style changes; the style at one time emphasizing legs, at another the bust, at another some other portion of the anatomy. The important or significant factor here is, however, that there is no discernible change in the female anatomy. For our purposes it has always had these components, and happily, probably always will. The change is only in its covering apparel. Thus, new knowledge, new form, or new utility is neither created by the style change nor induces that change.

On the other hand, take the electronics industry as a counter example. Change has been frequent in that industry, perhaps up to rate of change in the women's garment industry, but it has either been induced by or has resulted in new knowledge, new form, new utility. These, in turn, demand in that industry: new business enterprises, new

* Based upon a presentation to the American Institute of Chemical Engineers, Cincinnati, Ohio, December 8, 1958.

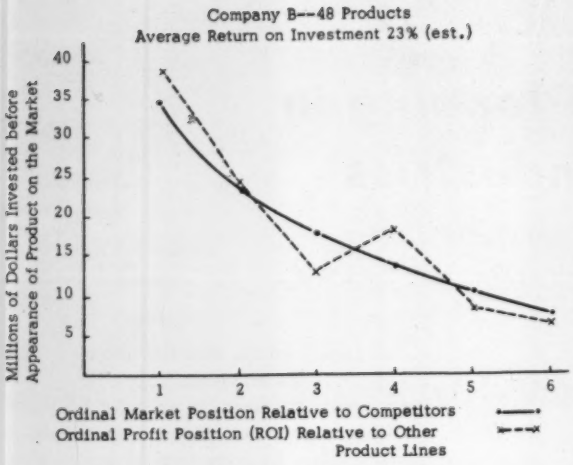


FIG. 1

equipment, new methods, differently trained personnel, etc. While some of the ideas and methods presented here may apply both to technical and non-technical industries, the emphasis in this analysis is on the changes, the underlying patterns, and the trends in the technical industries as these relate to Long Range Planning.

A CASE STUDY

The study which is reported here was cued by a large manufacturer's loss of market position and profit. (Call it Company A.) The loss could have been expected three years before it was felt, had top management been alert to the competitor's activities. But it would still have been too late to react and avoid the loss. Importantly, the whole mode of operation during these three years had been as good or better than before, so that the loss was not due to any deficiency in Company A's current operations. Its difficulty arose because it was not concerned with those long range activities necessary to keep its product and service competitive. The specific event which precipitated the problem for Company A was a smaller competitor's introducing a product based on far more advanced technology, and thereby virtually obsoleting the company's leading line of products. But, the lead had been lost several years before the competitor's product appeared on the market; indeed, it had been lost in the laboratory. Company A had to adopt an inordinately expensive "crash" program in order to regain its position.

It is to avert these kinds of reverses that long range planning is concerned. Day-to-day operations also need to be efficient, of course, but unless they are carried out within the framework of broad, well-conceived LRP, they will lead only to the efficient collapse of profit, leadership, and market position. The following material resulted from analysis of the trends and patterns in the company's industry, and provided the basis for a course of action which would provide the basis for long range planning and action.

Analysis of the evolution of the industry concerned here revealed a significant fact: *It is impossible to predict.* That is, it was agreed on presentation of the significant inventions and innovations in the industry in a chronology, that even the best informed scientists would have been unable to predict these events or even their incidence, plus or minus five years. The only predictable element was that there had been, and probably would continue to be, invention, innovation, and change, and that the relative frequency of these was roughly proportional to estimated Research and Development expenditures in the industry, lagged by some range of number of years.

The important Company A top management conclusion and policy in response to this finding were that: 1. The company should plan systematically to spawn a continuing series of these inventions and innovations as the basis for a viable, growing enterprise. 2. It should establish the mechanism for this continuing flow of inventions, innovations, and developments. This flow and the mechanism for it henceforth would be considered as important as the flow of materials, goods, and services in producing its current products and the mechanism for that flow, the factory.

At this point, the results of a study made in one of my former employments was introduced which reinforced the preceding decision. It also suggested a corroborative study of this Companys' different products. The purpose of the study was to determine the nature of the "game" which management plays in the long range; the strategies available, their expected pay-offs, and the mixed or pure strategy which should be adopted in the long range.

Figure 1 presents the results of the first mentioned study. This graph is interpreted as follows. Those products for which that former company was both in first position in its market and had highest return-on- (total product) investment, also were the products in which it had invested the most money in the product development (on the average) prior to the original appearance of the product on the market. This is an exciting finding: To make more money, spend more on new product R & D. However, before accepting the hypothesis unequivocally, the concept was tested by a similar analysis of Company A's products. The findings of this study are shown in Figure 2. The results are strikingly different. The meaning of the difference is clear. In Company A, large investment in advance of a product's first appearance did not tend to lead as strongly to first market position. Indeed, relative to some of its second place products, some of Company A's first place products had achieved their position with less advance investment.

The study to determine the reasons for the different tendencies gave the following qualitative observations on each company. Company B maintained an aggressive research and development program, with expenditures for

R & D very high as a percent of sales, circa 6%. Company A was proportionately almost as aggressive, as measured by R & D expenditures as a percent of sales. The difference here did not seem significant.

Company B, through its advertising, company slogans, etc., presented a corporate image of "making progress," where progress included innovation and commercialization. However, it did so very conservatively. For example, one of its former chairmen of the Board remarked, "Fifteen years is about the average period of probation, and during that time the inventor, the promoter, and the investor, who see a great future for an invention, generally lose their shirts. Public demand, even for a great invention is always slow in developing. That is why the wise capitalist keeps out of exploiting new inventions (2)." While the policy at Company B subsequently has advanced, it did so only by developing systematic procedures for evaluating when and how, in detail, to develop and commercialize an invention.

On the other hand, Company A, through its corporate image, slogans, and policies, better represents the pioneering inventor. There is good, though nebular, evidence that this image represents the personality and policies of the principal executives. This is a significant difference, even though it is of a qualitative character.

If the preceding difference in fact did exist, it should manifest itself in other more measurable ways. The following are some of those ways:

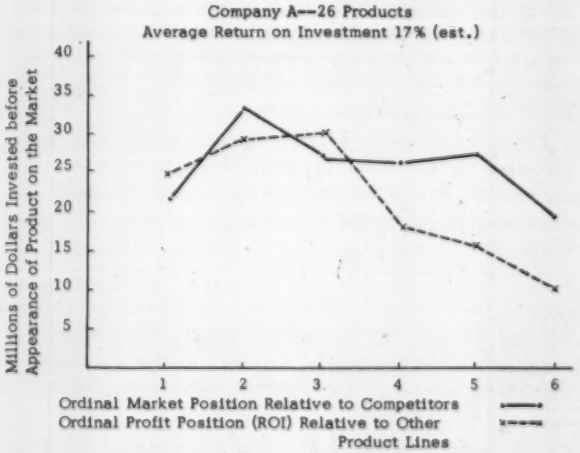
	Company A	Company B
1. % of R & D and engineering personnel in (a) Central Lab.	54	38
(b) Product Dept. Lab.	46	62
(Presumably reflects relative importance of product oriented and "business controlled" R & D personnel.)		
2. Average number of product lines per department or business profit center. (Presumably reflects the relative importance of any single product line to a single profit-responsible management team.)	6.4	3.1
3. % of product lines directly traceable through evolution to original products without acquisition or merger. (See Figure 3.) (Presumably reflects purposiveness and ability to commercialize on inventions and innovations arising out of R & D related to its existing businesses.)	47	72
4. % of products entering directly into the major overall system produced by the company. (Presumably reflects singleness of purpose in expanding its basic business.)	39	78
5. % of Engineering and R & D managers with training in management and business. (Presumably reflects commercial orientation in engineering and R & D.)	16	65 (estimated)
6. % of R & D personnel's time which may be self-directed. (Presumably this reflects relative amount of direction toward company objectives. However, Company B encouraged "wandering" as the means for detecting commercially promising inventions discovered outside its labs.)	12½%	20%

FURTHER STUDIES

These differences cued further studies on the process of innovation, including invention, development, and commercialization. In order to disguise the companies, but yet to give concrete examples of this process, the early experience of the General Electric Company is given. Most examples and references here are from (4), but interestingly they form a striking parallel to the situations uncovered in this study.

The key person in the process of innovation and commercialization is the engineer-entrepreneur, the person with technical training who can see commercial possibilities in the application of scientific principles and who labors to perfect usable products and techniques. This kind of entrepreneurship has become increasingly important as the advance of science has made available new knowledge, new products new production methods, and new resources. For in the long view the most significant manner in which to increase economic welfare (and company profit) is not through better administration of existing resources or (socialistic) change in the distribution of income, but through applications of science which increase national income.

Clearly, Company B is predominantly an "engineer-entrepreneur's" enterprise. It deliberately seeks opportunity to commercialize—mindful of the dictates of its chairman that without the test of marketability, any venture would be doomed to failure. It systematically extended its business through accretions always related to



Note: All data are disguised.

FIG. 2

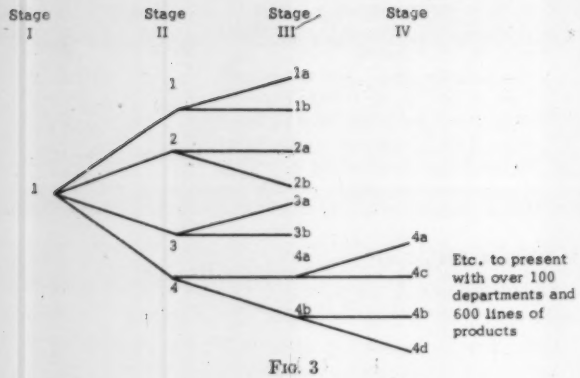


FIG. 3

its product line, and hence within the market and business which it knew well. Its engineering managers, as the above comparison indicates, have more training in and, presumably, understanding of the problems and methods of commercialization.

Another difference cited by the above comparison is the tendency to emphasize evolutionary entry into businesses. That is, Company B tends to enter companies through expansion into related products or through enlargements of the basic system which it produces and markets. For example:

> The economic orientation of Edison's inventive work in electric lighting defined his approach to the problem of subdividing the electric light (system). His goal was to invent a system which could produce light at the lowest possible cost. And his inventions were inventions primarily because he was looking for a low-cost lighting system. . . . Edison was the first inventor to realize that an incandescent lamp which could operate in a constant-voltage parallel circuit would necessarily have to be of high resistance in order to keep the cost of the copper conductors from being prohibitive. . . . Edison's work on the dynamo was also directed toward reducing costs. . . . In each case, he perceived the function of the component in the system. He then determined the characteristic of that component which would result in a *system* with the lowest production cost of light . . . the lamp, the dynamo, and the distribution network were designed to form a lighting system using the minimum amount of resources, with a meter in the system to assure it.

Through the above, we can see the evolutionary chain via which the now General Electric Company entered into its various businesses and product lines, virtually all stemming directly from Edison's original lamp, the protozoa of that company. The General Electric chain of evolution is portrayed in miniature, in Figure 3.

STAGE I

Edison developed the incandescent lamp which he wished to commercialize. Alone it had no future; as part of a complete system he saw it had large potential. This prepared for:

STAGE II

1. The lamp business "1" required supporting businesses to make and sell a complete lighting system, including:
2. A meter business to supply meters "2" and measure energy consumed.
3. A distribution network business to provide the distribution equipment "3".
4. An energy conversion (thermal to electrical) business, to supply electrical generation apparatus "4".

STAGE III

1. The lamp business, through research on lamps grew and spawned both indoor "1a" and outdoor lamps "1b".
2. The meter business involved measuring "2a" and instrumentation, thus leading via knowledge of instruments into the instrument business "2b".
3. Research and experience in distribution led to distribution hardware business "3a" through knowledge of electrical hardware, and its properties and manufacture. It also led to transformers for conserving copper losses, and thus to the transformer business "3b".
4. The energy conversion business led naturally to knowledge and experience in both prime movers (steam engines and turbines) "4a" and to generators "4b".

STAGE IV

To abbreviate, only a small number of the evolutionary chains are shown and the remainder of the narrative is reduced. Thus, at Stage IV, the prime mover business led to building the engineering and marketing knowledge and skills on which to enter both the steam turbine and gas turbine businesses (the latter of which proliferated later into aircraft gas turbines and shipboard gas turbines). The knowledge and skills in the generator business led directly to the ability to enter also the electrical motor business. While neither aircraft gas turbines nor electric motors are required in the electric incandescent lamp business, pursuit of the latter business by competent engineer-entrepreneurs led to accumulating the knowledge, skill, and insight eventually necessary for entering those businesses.

The full evolution to date (1959) has led to the General Electric Company with over 100 separate departments producing 600 lines of products in as many markets. Some evolutionary links have been terminal ventures, however. For example, governmental action restrained the Company from operating electric utilities; and, the Company found that, though it was helpful to finance these utilities, there was nothing in the skills of the engineer-enterpreneur which made him a good financier. Thus, General Electric withdrew early from the business of financing public utility companies, in order to sell its manufactures.

LONG RANGE PLANNING

Return now to long range planning, per se. Could Edison have visualized that his lamp business one day would have led directly to aircraft gas turbines and thence to rocket motors? Of course not, aircraft and rocket motors were unknown at that time. Even within much shorter periods, the links have led to unpredictable new businesses. If Edison, or any other scientist, could not forsee such basic events and turnings in his enterprise, how is it possible to plan for it in the long range?

The answer to the preceding question is in planning for the *flow of invention, innovation, and new businesses* which will evolve. This requires developing a deeper skill in and understanding of the processes of entrepreneurship.

Planning for specific inventions and their commercialization is short term, finite period planning. This short range planning requires knowledge and skill in the specific problems of the business to which the planning is directed. The longer range planning for the continuing flow of corporate life blood requires a broader set of knowledge and skills—such as:

1. The general principles of how to design business enterprises, so that whatever business evolves from invention and innovation can be profitably pursued or appropriately avoided.
2. How to recognize and develop not only required managerial talent, but more importantly, the entrepreneurial personnel to pursue new business.
3. How to set minimum, maximum, and expected rates of commercializable invention and innovation as the basis for growth and expansion.
4. How to determine criteria for branching at any node in the evolutionary chain, so as to enter only businesses which are compatible with acquired skills, knowledge and the collective self-image and corporate image.
5. How to determine the miscibility of different product lines and businesses into operating businesses.
6. How to establish the conditions and methods for effective entrepreneurship.
7. How to design the parent corporate structure and organization for the "flow of businesses" within that structure, from invention to innovation, to commercialization, and to replacement or abandonment, if appropriate.
8. How to perform the roles of chief executive and corporate staffs in a long range plan embodying the "flow of businesses." That is, how to manage entrepreneurs, rather than how to manage other managers or individual contributors.

These areas of knowledge and skill would require many more pages to develop than are available here. However, a paragraph may be reported on each, as follows:

1. *Principles of design of business enterprises.* This area is amply covered by the numerous texts and papers on business organization and management, together with the literature of managing the functional components therein. However, one important lack is techniques for the integration of the various function components into a single system, in the same manner that the engineer performs the system integration and synthesis function in designing a complex system. The newly developing techniques in operations research have important application in the rational design and synthesis of business enterprises; as for example those being developed in the Operations Research and Synthesis Service at General Electric. Perhaps the existence of this service at General Electric reflects that Company's unusual awareness of the need to bring to bear the most advanced, and powerful techniques of science and engineering in designing the many evolving businesses within its corporate structure. Toward this objective, and in a separate paper (5) I have attempted to describe methods and techniques for designing business organizations dynamically, in the same manner that engineers must design systems to both static and dynamic criteria.

2. *Development of entrepreneurial talent.* The training and development programs for business are directed toward "managers," the entrepreneur is hardly recognized. Yet, as Passer relates, "(he) is the key person in this process (of founding and growing new industries based on new technologies)." Unfortunately, the entrepreneur often may be greeted with untoward attitudes in established businesses, unless those businesses are organized to grow on the entrepreneur's labors.

For example, Maclaurin (3) writes,

> Innovations, in fact, may be becoming inherently more difficult. The current trend toward emphasizing smooth human relationships as the principle qualification for administrative responsibility tends to militate against the rise of innovators (entrepreneurs) to top positions.

To innovate and commercialize an invention or discovery, the entrepreneur necessarily must alter many facets of his environment; change is his function, and new business his output. But, the capacity to change, or even to disagree—the first step in effectuating change—is a scarce commodity.

Torrance (6) comments on the modern military entrepreneur, the Jet Ace:

> Research findings indicate that certain individuals show a generalized willingness to oppose others and disagree when the situation requires it. In our studies of Jet Aces in Korea, we found that this characteristic was typical of the Ace when compared to his less successful colleagues. Asch demonstrated a rather alarming similar picture. In "brainwashing" susceptibility experiments, Asch generated a disagreement between individuals and small groups on a clear and simple matter of fact in the environment. Only one fourth of his subjects adhered to their own correct judgements, when confronted with the different and erroneous judgements of the (experimentally guided) groups.

(The experiments involved deliberate expression of erroneous opinion by the group to determine whether the subjects would maintain their correct opinions. *Three-fourths did not.*)

To plan in the long range requires planned cultivation of entrepreneurs—those who can induce necessary change and who have the other moral and intellectual qualities for business leadership. Unless this key ingredient is provided, the best plan will remain dormant for want of the entrepreneurial spark.

3. *Rate of invention and innovation.* One of the principal findings from the study reported here is that there is a measureable rate of decay of the value of information as contained in products, processes or methods. This is sometimes referred to as obsolescence. However, to recognize it as a problem in maintaining the continuous flow of new information gives the manager and the scientist (or engineer) a better basis for planning the R & D program, for planning the discovery and flow of new information, for anticipating the competitive decay of previously produced information, etc. The consequence of this insight in the study reported here was to study and project the trend in information decay rates, and to

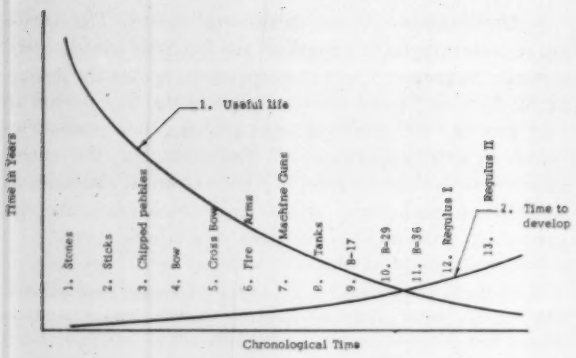


FIG. 4

estimate the magnitude of the R & D staff and reinvestment required (a) to maintain fixed relative position (b) to gain relative to competitors, assuming both their continuing at current rates and their accelerating their overall reinvestment. The general nature of the findings on information decay rates are illustrated in Figure 4, and provide illuminating insight on the cost of remaining competitive and progressive.

To protect proprietary information, a weapons systems example is used, and the relative time span is expanded. However, the same trend was observed over short time spans and for a number of commercial products. To illustrate, curve A indicates the useful life of successive competitive weapons systems. Curve B indicates the time (or can be cost) to develop those systems. For example: Nelson's tiny flagship was 40 years old and still a first-rate ship-of-the-line at Trafalgar, Halsey's giant Enterprize at three years of age was obsolescent before World War II. The B-17 took circa four years to develop and was operational seven. The B-29 took about six years to develop and was operational four. The B-36 was ten years in development and operational only three. The Navaho was in development six years; it was abandoned before completion because of obsolescence. Regulus I and Regulus II had similar short lives.

Obviously, the increasing cost of R & D and the decreasing life spans of products counteract each other. The former tends to decrease a company's ability to do R & D; the latter increases the need for it. In between these, the rate of commercialization of inventions, then, needs to be controlled so as to insure an optimum program, balanced between the different phases, e.g., R & D, capital investment, advertising, market research, etc. Inasmuch as the problem of balancing and timing the various programs can be phrased in functional equations, it either becomes amenable to solution by calculus of variations, i.e., dynamic programming, (1) or these concepts greatly aid judgment solutions.

The problem is somewhat complicated by the fact that the production or discovery of inventions has elements of uncertainty. This, however, is not difficult to handle if expected, minimum, and maximum rates are used and boundaries or tolerance limits are used in the computation. For example, an upper bound(s) may be used to help delimit the number and variety of programs which can be undertaken with available resources. The lower bound(s) determine minimum innovation necessary to maintain given levels of competitiveness. That is, the control of the flow of ideas is instrumental to corporate health; it must be neither too little nor too great.

4. *The criteria for business branching.* The General Electric Company's experience indicates that skills and knowledge are highly transferable, vide the branching and growth from lamps to such things as toasters, turbines, and transformers. However, some branches failed. The successes and failures together provide excellent guide lines. The following are key elements in predicting the success or failure of a branch.

a. Environmental or institutional knowledge. A working knowledge of trade practices, market characteristics, channels of distribution, contacts with key persons may provide at least part of the basis for a successful branching. For example, National Cash Register Company has had no prior background in large scale computers. But its very close ties to an important market via a formidable marketing organization well may permit it successfully to enter the business computer field. It offers a point of entry into that business as the business data processing technology expands and requires integration of the point of initial recording more intimately in the over-all data system.

b. Technical knowledge and skill. A prime example is General Electric's entry into the electric motor business. An electric motor is essentially a generator run in reverse. Thus, the technical knowledge and skills to design and manufacture generators, provided a strong platform for entering the motor business. The basic data involved in the industrial analysis for this kind of branching are similar to those described at this meeting by Dr. Igor Ansoff. The method described in that paper was used by Markowitz and Rowe as the basis for economic and military mobilization planning. The value of the analysis can be large: one company planned to branch into a business but found that the commonality of skills was only apparent, not real. It planned to operate a far-north aircraft engine repair station in the summer and a diesel repair station there during the winter while the diesel tractors were idle. Unfortunately, the skill carry over from diesel to aircraft parts was too great; the mechanics repaired diesels to aircraft specifications, and vice versa. This was, of course, too costly and inefficient, and had to be abandoned.

c. Self-image and business flexibility. The self-image to which we refer here is a concept familiar only to those acquainted with psychoanalytic theory. Virtually only those individuals who have been sucessfully analysed will understand their self-images, and control the operation

of them as the determinant of overt behavior. Others are conscious of their self-images only to the extent they are or are not able to engage in one or another type of social, occupational or other roles, but are not conscious of the reasons for their role inflexibility. An example is cited of a manufacturer of copper hardware that successfully competed in an industrial market where one pattern of occupational roles was required. The company was not successful in a commercial market, primarily because their collective self-images unconsciously made them seek defensive refuge behind the mask of being "conservative engineers." While they consciously rationalized their preference for this role, to the trained observer it was obvious that it was a haven of defense against the incurrence of tensions and anxieties, induced by departing from their protective role. This unconsciously imposed inflexibility caused their commercial operation to be inefficient and unprofitable, even though the company already possessed a strong platform in manufacturing skills and facilities required for that commercial business. Role inflexibility problems often are resolved by "decentralization" so that each autonomous group, within the same company, can identify with that role(s) implicit in each of the several businesses which is compatible with the group's collective self-image. An alternative, which was used, at least partially in this instance, is a psychoanalytically oriented training program to increase the personnel's flexibility to move between different roles. The organization, in this case, was not large enough to decentralize, hence required multiple role flexibility, through personal flexibility.

The summation of the collection of self-images is the corporate self-image. This latter is one of the most powerful determinants of corporate flexibility—both because it reigns and operates through the unconscious and, hence, cannot be reasoned and reckoned with (except in analysis), and because it is self-reinforcing. No matter what course of action is followed, or attitude projected, they tend to be self-reinforcing: the negative attitudes to be negatively reinforced and the positive, postively reinforced—precisely because one or the other attitude already eixsted. Hence, the results of performing any business role is to enter that role with such unconscious predilections as create the responses from the environment which tend to confirm the predilection, in favor of or against the role. Obviously, the greater the role flexibility of an individual, or of a business, the greater is its ability to capitalize on opportunities, regardless of the roles which they require. It is of little value to develop long range plans and programs, only to find that a variety of apparently unrelated obstacles interpose themselves. These may take the form of "that is not our line of business," "the risk is too large," "the economy is uncertain," or other. Alternatively, they may appear as simple inaction, or delay. While it is possible to develop systematically the capacity for role flexibility, it is beyond the scope of this report to describe.

d. Joint or by-products. A frequent basis for branching is when the production processes yield joint or by-products. This concept is obvious and needs no elaboration here.

The preceding are subject also to legal and moral limitations. For example, General Electric has been restrained by antitrust action from operating public utilities; the aircraft manufacturers from operating airlines, etc. However, these concepts illustrate the evolutionary chain and branches in the growth and diversification of typical, successful, large companies. To reiterate, long range planning for such growth, requires as much the maintenance of the conditions for, and skills of, entrepreneurship as it does the development of specific action programs. Edison, in 1885, could hardly have planned for the evolution of the G. E. lamp business into the toaster and aircraft gas turbine businesses. But he and his successors, by maintaining the conditions for and skills of entrepreneurship assured that evolution.

SUMMARY

It was mentioned earlier that there is a minimum regeneration required for maintaining a viable business. Investment in innovation (as in R & D, new markets, new products, or other) must be at least a certain minimum in order to sustain competitiveness and viability. In studying this phenomenon, the following observations were made. There is a distinct, quantifiable, and measureable input-output relationship between successive stages in an innovation cycle. It was found that the "transfer function" can be used in long range planning. Graphically, it is shown in Figure 5.

Several important relationships can then be sought for planning purposes. Some of these are:

1. What is the average, minimum, and maximum ratio of the area under each curve to the area under the preceding curve?
2. Is there a trend in these ratios over a period of time; are they increasing or decreasing?
3. What is the characteristic lead-lag relationship between the curves?
4. Do the ratios vary from product line to product line; and, if so, how?

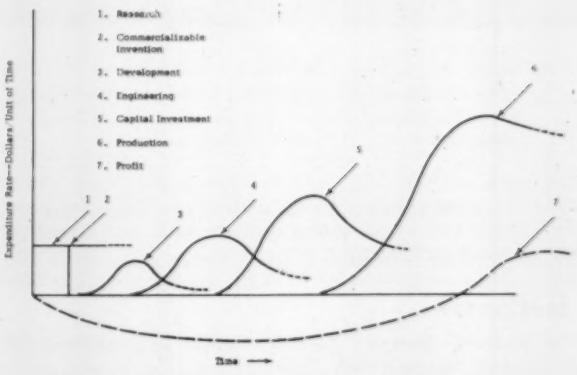


FIG. 5. Innovation Cycle—Expenditure Patterns.

This study was cued by an engineering occupations remuneration study. There, for example, it was found that the higher the rate of innovation in a branch of engineering, the higher the starting and top rates of pay. Similarly, it was found that the higher the rate of innovation in an industry—up to an upper bound—the higher the return-on-investment. It was found that the correlation between R-O-I on a series of products, as a function innovation investment, was not as high as it was on an industry basis. It appeared that there was random fluctuation on a product basis, which was averaged out on an industry basis. In particular, in a whole industry there is opportunity for the operation, not only of primary breakthroughs, but also of supporting or facilitating discoveries. Thus, it appears that whole industries tend to move together, while within these broad movements, the more aggressive innovators lead. But, the leadership tends to be paced by the whole complex of limiting and facilitating innovations and advances.

In broader perspective, long range planning must answer the question as to the division of innovational resources between:

1. Those programs which lead to lower cost (proportionately less employment).
2. Those which lead to more products.

In the broad perspective, this is important: if the rate at which the work force is displaced through technological innovation is greater than the rate at which new employment is created on new products and services, unemployment is an inevitable consequence. In a political democracy with free enterprise, this balance can be maintained best through those free enterprises so planning their activities that the opposing tendencies are equilibrated. The alternative is social action, i.e., socialism.

In summary, long range planning requires or achieves the following:

1. A business-wide perspective in innovation.
2. A continuing flow of innovation for business viability and profits.
3. A set of skills and conditions for successful entrepreneurship within the corporate framework.
4. Organization components for pursuing the processes of entrepreneurship.
5. Adapts the collective or business self-image to the roles implicit in foreseeable and evolving businesses; either through increasing personal flexibility or through organizational isolation of the roles (i.e., decentralization).
6. A balanced flow of resources to the phases in the innovation cycle.
7. Recognizes and plans for the gradual reduction in the direct labor force to the indirect and overhead, as the result of technological progress.

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Management and Industrial Engineering in the Coal Industry*

by DAVID L. FRANCIS

President, Princess Coals, Inc., Huntington, West Virginia

MANAGEMENT and Industrial Engineering, while getting a late start in the bituminous coal industry, are becoming increasingly important and are recognized as a valuable staff service in more companies each year. It is my purpose to outline how we use Industrial Engineering within our coal industry, and how some of our major problems are approached and solutions are developed.

Management engineering and Industrial Engineering are in many ways synonymous except for their areas of application. I have always felt that management engineering applied to over-all industry or company top management level work in the areas of organization, functions and responsibilities and the developing of the basic philosophies and policies as to the future courses that an industry or company within the industry should take. This is contrasted to Industrial Engineering which is specific within a company and which is applied to organization, operating methods, and procedures.

Our industry has used management engineering firms from time to time in making studies of over-all problems. As an example, several of our companies participated some six or seven years ago in a study of the future domestic sales for coal throughout the eastern half of the United States. This study bore out some interesting conclusions; namely, that as we generally knew, the hand-fired market was dwindling; the home stoker market was remaining constant; but they found for us, which we did not know, that the commercial business—hotels, apartment houses, etc.—was using more and more of our prepared size coals each year. So through them we found a growing market and were able to fortify our own planning.

Tomorrow in Huntington a group of operators will hear a report by a management engineering firm on a reorganization proposal for our National Coal Association and some of the associated organizations which they are recommending merging with National Coal, it being the desire of some of the leaders in our industry to see that our national organization is strengthened and made more effective by a reorganization. I happen to know that some of the major recommendations include a streamlining of present national coal functions with other outside organizations, establishing six major divisions in National consisting of Marketing, Research, Transportation, Public Relations, Government Relations, and Finance. Certainly with the trying problems which have confronted our industry for the last few years, we need to make every effort to see that our over-all industry approaches are coordinated and streamlined.

In coal mining, like many industries, the pre-war use of Industrial Engineering was limited. Before 1935 only one or two coal companies had employed the technique in a special or specialized manner. From the late 30's on, this is the period when mines in our area first began to use Industrial Engineering, the trend nationally really hit its stride. Coal along with many other industries participated in a remarkable growth of the field. However, even today the number of coal mining companies with Industrial Engineering offices is probably a modest percentage of our industry. However, the cliche that contends that "our business is different" is heard less frequently. Our severe competitive position is modernizing the management practices rapidly.

MANAGEMENT ENGINEERING WITHIN OUR COMPANY

Only one other company besides our own has ever had an office of management engineering. We recently started one and it is now staffed by an individual who some years ago was Industrial Engineer at our Princess Elkhorn operation. His major functions and responsibilities are outlined as follows:

1. *Function*

To assist the President in coordinating various aspects of the business (sales, production, finance) with special emphasis on organization studies, establishment of policy; review of results; summarizing such data so that the President can manage by exception.

2. *Supervises*

None. May use services of the operating, sales, and financial staffs in obtaining data for special purposes.

* Based upon a presentation to the Charleston-Huntington Chapter of AIIE, April 20, 1959.

3. *Duties*

a. Make studies of organization structure with particular emphasis on the need for the function, staffing requirements, and administrative practices.

b. Assist President in establishing basic objectives for the company and for the various departments of the company.

c. Provide a system of reporting so that measures can be made of progress toward the attainment of objectives.

d. Appraise organization performance and, working with department heads, assist in preparing plans for improvement.

e. Establish a management development program covering all departments of the company and insuring that qualified personnel are being developed for the various administrative positions which must be filled in the future. As a part of this function, encourage training programs to improve performance on present jobs.

f. Document the organization structure and keep it up to date by means of an Organization Manual containing organization charts, position descriptions, and basic company policies.

g. Assist President in preparing long range planning studies.

h. Analyze interdepartmental procedures to insure that they are efficient and effective and prepare releases to all concerned.

i. Design and install a system of management controls and administrative reports to the end that all department heads are kept informed of performance during previous periods and the areas in which improvement is needed.

j. Coordinate the annual management review and improvement program.

From time to time in the past, averaging every three years, our company has employed a management engineering firm to come in and study some facet of our business. They have gone through our sales, maintenance, accounting and warehousing. We now feel that with a permanent management engineering office a great deal of this can be done more effectively within our own company and at a much lower cost. Just as our over-all industry problems need sprucing up and pointing up, so do we need to do the same within our own company. This, plus long range planning and coordination between production and sales, will effect a material improvement in our over-all profit picture.

INDUSTRIAL ENGINEERING

In terms of degrees of application, our version of Industrial Engineering is less detailed and less occupied with the fine measurement of work than is the average manufacturing plant. Of course, effective utilization of our production man hours requires time study. However, lacking the multiplicity of operations found in manufacturing, we do not usually accumulate the voluminous data typically found in the factory.

Time study serves to establish for us element times for our basic work cycles. From these facts we determine the existence of crew unbalance, develop methods of improvement, establish production standards, and analyze substandard performance or conditions. A definition of methods engineering stated 25 years ago by Harold Maynard characterizes our form of application:

> Methods engineering is the technique that subjects each operation of a given piece of work to close analysis in order to eliminate every unnecessary operation and in order to approach the quickest and best method of performing each necessary method of operation; it includes the standardization of equipment, methods and working conditions; it trains the operator to follow the standard method; and when all this has been done, . . . it determines by accurate measurement the number of standard hours in which an operator working with standard performance can do the job. . . .

Method improvement is our main theme. Careful inquiry and investigation are a necessity if you are to find a better way of doing a job. We look to the Industrial Engineers as a focal point for new ideas and to keep abreast of what others are doing in our industry. From information acquired through trade periodicals and from field trips into other mine operations, several analytical reports are prepared annually.

In collaboration with other members of the management team, the Industrial Engineers are the medium whereby a substantial portion of ideas and plans for cost reduction and changes in methods and procedures are originated and carried through.

The major functions and responsibilities of the Industrial Engineering Director are outlined as follows:

1. *Reports to and Supervises*

The Industrial Engineering Director reports to the Staff Director and supervises the assistants in his office.

2. *Scope and Objectives of Position*

The Industrial Engineering Director serves management by providing information and data through time studies, investigations and inspections; he summarizes his findings in his reports and indicates the weaknesses and faults in the production cycles; he observes opportunities for improvements in methods and makes suggestions for improvements; recommends ways to increase production and lower costs through the most efficient use of machinery, equipment and manpower. Keep the necessary records of his studies, production performances and all other pertinent data in order to furnish management with constructive and reliable information.

3. *Responsibilities, Authorities and Duties Concerning Safety*

The Industrial Engineering Director must be continually safety conscious, and in so doing shall:

a. Obey all safety regulations in the mines when performing his work and traveling therein.

b. Report any unsafe conditions that he observes and recommend their correction.

c. Consider the safety factor in planning or revising operating methods.

d. Require the observance of all safety rules and practices by the men under his supervision.

4. *Responsibilities, Authorities and Duties Concerning Manpower*

The Industrial Engineering Director maintains relations with those directly under his supervision as well as those with whom he comes in contact while making studies, and in so doing shall:

a. Train newly employed Industrial Engineers to analyze mining conditions and mining methods, and in the technique of time studies.

b. Observe the ability of hourly men during his studies and recommend to the General Manager promising prospects for supervisory positions.

c. Suggest changes in sectional lineups to the Mine Foremen whenever he believes improvements will result therefrom.

5. *Responsibilities, Authorities and Duties Concerning Operations*

The Industrial Engineering Director, in performing his work, shall:

a. Make analyses of physical conditions in sections and determine the effect of unusual conditions on production.

b. Shall suggest to the Mine Foremen and Superintendents certain specific methods that are successful in one mine and which may have a direct application in the other mines.

c. Make time studies of new methods or of old methods that are not up to production standards. Analyze these studies and make recommendations for operarting improvements.

d. Serve as spokesman for the Industrial Engineering office in his trips to the various sections by explaining methods and policies of his department to the operating personnel, especially in regard to the setting of production standards for sections.

e. Make detailed and analytical reports of sections as to physical conditions and operarting methods.

f. Whenever convenient, handle special assignments within the mine at request of operating personnel such as analyses of supply distribution, haulage problems or face preparation.

g. Make studies of tipple operations.

h. As far as able, report on care and condition of equipment.

i. Prepare each week reports on performance showing ratio of production to standards, delays and their effect.

j. Prepare monthly for management, reports showing in detail improvements or poor showings of mines and sections and giving reason for same as determined by his department's studies.

k. Make visit to mines and plants of other companies to see new equipment in operation and to study their methods.

6. *Responsibilities, Authorities and Duties Concerning Relationships*

The Industrial Engineering Director cooperates with others from within and without the company for attainment of common objectives, and in so doing shall:

a. Cooperate with the operating personnel on the sections by pointing out ways and means of improving production.

b. Cooperate with the Mine Foremen and Superintendents by making special time studies for them.

c. Cooperarte with all departments by making special studies and providing reports whenever requested.

d. Cooperate with the Maintenance Superintendent in preparing change-out schedules and analyzing delays.

e. Cooperate with the Staff Director and supply him with reports of studies.

ORGANIZATION AND PROCEDURES

An organization chart of one of our companies or divisions is shown in Figure 1. This is fairly typical of our mine organization and gives you a fair picture of where the Industrial Engineering office is located. One of our original jobs for this office was a careful study of our organization to see that lines of authority were clear-cut and to prepare for each supervisor a write-up of his functions and responsibilities.

At each of the six divisions of our company, our supervisors have now or have in preparation manuals of operation which set forth details of operating methods and procedures. Although we experience the usual organizational task of having the manuals used and lived up to, to the extent that we would prefer, we feel that we do get tremendous benefits from the planning of a procedure, by writing of it, and from the discussions it stimulates. These blueprints of operation are also very helpful in training a new supervisor. The writing of manual procedures takes a specific talent and is sufficiently exacting to be good training. Our Industrial Engineer becomes better informed on the organization of a division when he writes a procedure.

SUPERVISORY INCENTIVE PLAN

All of our supervisory employees participate in an incentive or bonus plan of some type. The Industrial Engineer is directly responsible for the administration of the incentive plan for the mine foreman, maintenance foreman and section bosses. At this point mention should be made of the hourly employee status as related to wage incentives. You no doubt know that incentives are prohibited by the United Mine Workers union. Many coal companies nevertheless have an incentive plan for their supervisors. Coal is mined with the use of several units or seperate crews in a mine. Each unit (8 to 10 men) has a foreman or section boss, as he is known in mine language. Inasmuch as the hourly employees are on daywork, we obtain an indirect incentive effect on the crew by providing for the foreman a stimulation for improved productivity.

Regular evaluation of underground mining conditions is made by the Industrial Engineers to keep current the tonnage standards assigned to each section. Performance reports published weekly and monthly furnish management with a measure of productivity. Where a weak performing unit does not respond to routine followup by line supervision, a study of the unit may be called for. A detailed record by the Industrial Engineers of a full shift's activity can usually reveal the causes for substandard performance.

The incentive plan is not complicated. When a production section reaches 82 percent of the production standard the section foreman starts sharing the profit on an ascending pay curve. Our foremen will average a bonus of $75-$100 per month. This is approximately a 15 percent addition to their base salary.

Generally we find a correlation between performance and supervisory quality. Although "the cream rises to the top" principle in personnel is still valid, the existence of documented and accurate records of performance provides a valuable basis for sound personnel evaluation.

PREVENTIVE MAINTENANCE PROGRAM

About five years ago our maintenance superintendent and our general manager at the Princess Elkhorn Division developed, with the assistance of a management engineering firm, a preventive maintenance program patterned after a plan used in the aircraft industry. That industry calculates the life of a piece of equipment or component part, based on actual practical experience. A frequency of overhaul is then scheduled to prevent the occurrence of a breakdown or failure. Our Industrial Engineering office had a large part in this development. An extended analysis was made of each type of equipment to learn accurately its performance history, what parts were most troubled, and what breakdown causes were affecting the equipment. From this basic information the procedures and change-out schedules were devised. A master schedule board is the main control of the plan. Although

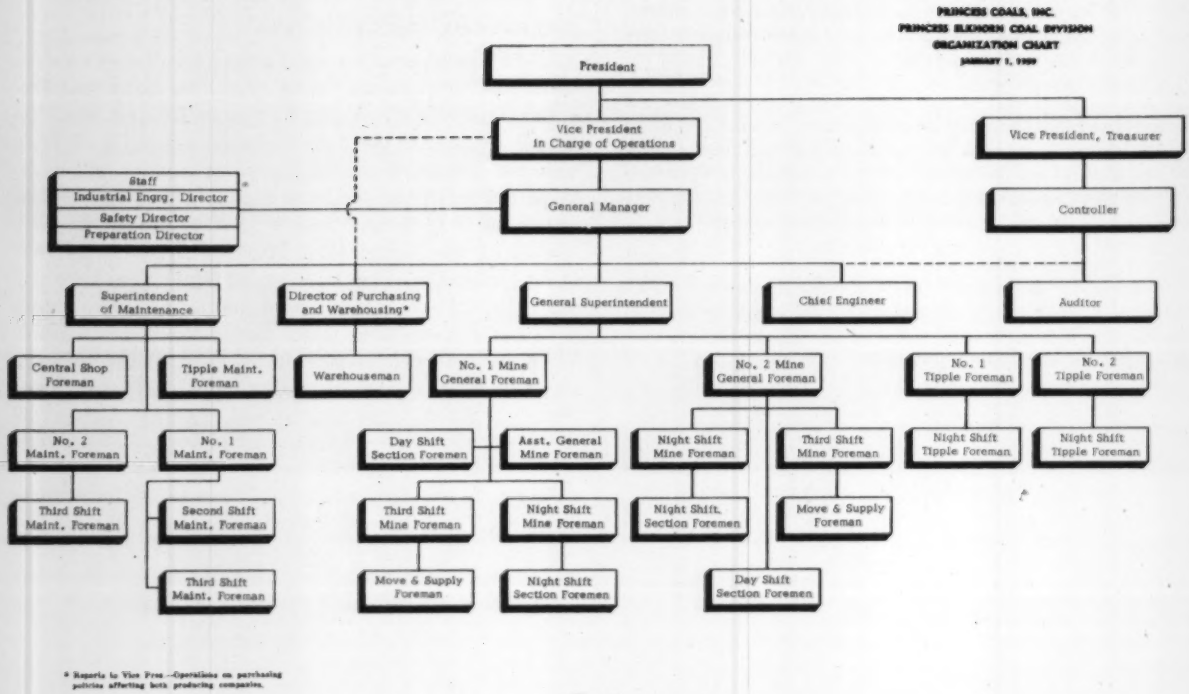

FIG. 1

the function of the program is the responsibility of the maintenance superintendent, the Industrial Engineer can be a constant observer of the scheduled activity and review regularly all emergency or non-scheduled maintenance work.

This program has been of material assistance to us in reducing our downtime. In addition, we accomplish considerably more and better maintenance work when it is done in our outside shop. Underground repairs are usually made under adverse circumstances. We are using mobile equipment in all underground operations. We mine in coal seams averaging down to 32" in thickness. Each section crew is operating four large pieces of equipment in a confined area. The equipment is constantly on the move and is working in all the variations of grade, mud, water, and rock that the natural conditions of a mine impose. Cutting and loading of coal is now a fast moving operation and requires rugged equipment to withstand the severe wear. Our section crews spend an hour per eight-hour shift in traveling to and from their underground work places and in performing the usual start and stop duties at the beginning and close of the shift that all jobs entail. Production time for us assumes therefore extra value. Broken down equipment a mile underground cannot be endured too often.

WAREHOUSING AND SUPPLIES

Our Industrial Engineers also have done much to affect improvements in warehousing and supply. We have modernized our warehouse procedures and inventory controls. Supply budgets have been very carefully evaluated and established so that our cost in this area is more carefully controlled. I won't go into detail here because you are acquainted with this type of operation in your own industry.

TRAINING PROGRAM

An old principle says that cost control must mean cost reduction. Since it is people who spend the money, then only through people will costs be controlled.

Fundamental to the life of any business is an awareness by its people of the costs of materials used and of work done. A knowledge of the costs must be matched with a knowledge of what to do about managing them. Industrial Engineering at this point provides a valuable service to supervision.

In the Industrial Engineering office we try to keep one trainee who is a young man and has earned his mine foreman's certificate, thus certifying him to perform as a section boss. We find that if these men have a minimum of two months in this office they get a new and better understanding of management problems. Bear in mind that these men have been good union members all their working years and are without supervisory experience or training. By familiarizing them with the Industrial Engineering office and its procedures, these trainees gain a wide range of knowledge as they are introduced to the many facets of the organization. During this period we use these

men as relief foremen covering absences of regular supervisors. A smoother transition into the supervisory role is achieved. We have proved the superiority of this type of trained man over those who are pulled right out of the ranks to begin their supervision without such training.

CONCLUSION

I have given you a few examples of the type of effective work that our Industrial Engineering offices are performing. Certainly these offices are a very valuable and integral part of our working organization and management team.

Our industry needs much more of this type of analysis. Industrial Engineering is so different from the type of planning and thinking that the superintendent or foreman have to do or even have time to do. A supervisor, loaded with his daily routine, does not always have enough opportunity to sit and think and plan. A staff man can fulfill this need and can be objective about all the factors. A more completely developed program and conclusion is the result. Industrial Engineering must always rely heavily on the supervisor and cooperate with him very closely.

Only by using a major part of our profits to buy new and better production equipment can we keep our company strong and competitive. We would not be in business today, combatting high costs and a weak market, if this policy of profit reinvestment had not been followed through the years.

When we spend these dollars, which represent much work on the part of a lot of people, thorough preparatory study is needed. Information and analyses by the Industrial Engineers help to decide what we should buy. Currently, for example, three large mining equipment manufacturers are selling new low coal loading machines. Each of the loaders will have several good features. Which one will do the best job for us? We will learn this answer by performance trials. From the information obtained and analyzed during these efforts, a decision will be made. An important part of our future rests on how good that decision is. Furthermore, once new equipment is bought there is often another series of studies required to bring the equipment to its expected performance.

Thus, it is proper to conclude that the type of work being done by the Industrial Engineer, not only in our industry but in others, is a most valuable adjunct to progress. Frankly, I don't know how a company can get along without Industrial Engineering. You should be proud of your profession. The art of Industrial Engineering is advancing. This qualitative growth brings larger challenges and opportunities.

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Obsolescence and Economic Lot Size

by R. C. GRASSI

Associate Professor of Industrial Engineering, University of California, Berkeley

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ONE of the problems confronting a manufacturer is to produce enough pieces on a given set-up so that the sum of the unit set-up cost and the unit storage cost is minimized. If a large number of pieces is produced the unit set-up cost is small and the unit storage cost is large; conversely a small number of pieces produced results in low unit storage cost and high unit set-up cost. Economic lot size determination serves as a guide to minimize these cost components.

Camp presented (1922) a general formula to determine economic lot size so that the sum of the unit set-up cost and the interest on stores investment would be a minimum (1). Subsequently Raymond, Lehoezky, Norton, and others developed more specialized formulae but the approach remained the same: namely, minimize total unit cost by considering the cost components which vary directly and inversely with lot quantity. These methods differed mainly in the definition of the various cost components.

Obsolescence was considered initially in economic lot size determination by Parrish as a portion of the cost of carrying inventory (1). For the case of lot size determination in the aircraft industry, Chambers, Leake, and Bond considered obsolescence in a probabilistic manner (3). However, it appears that obsolescence has not previously been considered in the manner presented here. The economic lot size formula developed is general in nature and clearly shows the significance of obsolescence in economic lot size determination.

When goods are produced at a rate greater than consumption there is a risk that unconsumed goods may subsequently be unsuitable for consumption. Obsolescence is only one of the phenomena which can render unconsumed goods unsuitable for consumption; others being fire, theft, and insurable events. However, some manufacturers of durable goods incur obsolescence through design changes more often than for other causes. The design of parts or components may change from time to time for a variety of reasons, the most prevalent being to improve performance and/or appearance, and to facilitate manufacturing.

OBSOLESCENCE

In the investigation from which the data were obtained, parts unconsumed subsequent to design changes (inventory) are considered obsolete and are either scrapped, re-worked, or used for service requirements (2). In any event it is ordinarily undesirable to use obsolesced parts for production and the presence of such parts results in a capital loss.

The history of a part which has undergone one or more obsolescences will be marked by one or more terminated life spans and an unterminated life span. The terminated life span of a part can be determined by the time interval between the dates of inception (birth) and obsolescence (death). The unterminated life span of a part is taken to be at least equal to or greater than its present life, the time interval between the date of its inception (birth) and an arbitrary reference date.

Consider a total of n terminated and unterminated life spans of length $Ti (i = 1, 2, \cdots, n)$ associated with a group of r parts such that $n > r$. A plot of the relative frequency with which a terminated or unterminated life span of length $Ti \leq t$, can be constructed. In an actual case (2) the relative frequency was simulated by an exponential probability density function, defined by $f(t) = \alpha e^{-\alpha t}$. An estimate for the parameter α can be determined by maximum likelihood estimation. The joint probability density function, $P(Ti)$, of the n observations is

$$L = \prod_{i=1}^{n} \alpha e^{-\alpha t}$$

$$= \alpha^n \exp - \alpha \sum_{i=1}^{n} Ti$$

$$\ln L = n \ln \alpha - \alpha \sum_{i=1}^{n} Ti \ln e$$

$$\frac{\partial(\ln L)}{\partial \alpha} = \frac{n}{\alpha} - \sum_{i=1}^{n} Ti$$

Differentiating and equating to zero results in

$$\frac{1}{\alpha} = \frac{\sum_{i=1}^{n} Ti}{n}.$$

Thus, $1/\alpha$ is estimated by the sample mean of Ti,

$i = 1, 2, \cdots, n$. Since

$$E(t) = \text{(mean life)} = \int_0^\infty t\alpha e^{-\alpha t}dt = \frac{1}{\alpha}$$

the maximum likelihood estimate for α is the reciprocal of the expected life span of the "obsolescence rate"

$$\alpha = \frac{n}{\sum_{i=1}^{n} Ti} \text{ obsolescences/unit time.}$$

With the assumption that the r parts will tend to behave in the future as in the past (2), obsolescence can be considered explicitly in determining economic lot size for the r parts by means of a probabilistic cost function.

COST FUNCTION

Assuming goods are intermittently produced for inventory and are withdrawn from inventory continuously at a uniform rate and that the production rate is very much greater than the usage rate, the inventory posture becomes the classical saw-tooth pattern. If Q is the production lot quantity and B is the buffer stock quantity the unit production cost may be expressed as

$$P = D + \frac{S}{Q} \qquad \text{Eq. 1.}$$

where D is the sum of the unit material, labor and overhead costs, and S is set-up cost per lot.

The annual inventory cost is the product of the mean inventory $(B+(Q/2))$, the unit production cost given in Eq. 1., and the annual inventory charge rate, β. The unit inventory cost I is given by

$$I = \left(B + \frac{Q}{2}\right)\left(D + \frac{S}{Q}\right)\frac{1}{R} \qquad \text{Eq. 2.}$$

where R is annual part requirement.

To find the expected unit cost due to obsolescence it is necessary to consider the exponential probability density function

$$f(t) = \alpha e^{-\alpha t}.$$

If a lot of size Q is manufactured when a part is at age A years, the lot will be used up when the part reaches age $(A+(Q/R))$ years. The probability that the part will obsolesce during an infinitesimal time interval $d\tau$, occurring at a time τ after A is the conditional probability density that the part will obsolesce during $d\tau$ given that the part was alive at A years.

$$P\{(A+\tau) \le T \le (A+\tau+d\tau) \mid T \ge A\} = \frac{\alpha e^{-\alpha(A+\tau)}d\tau}{\int_A^\infty \alpha e^{-\alpha t}dt} = \alpha e^{-\alpha\tau}d\tau. \qquad \text{Eq. 3.}$$

The expected number of parts lost due to obsolescence during $d\tau$ is the product of inventory during $d\tau$ $(B+Q-R\tau)$, and Eq. 3.

$$(B + Q - R\tau)\alpha e^{-\alpha\tau}d\tau. \qquad \text{Eq. 4.}$$

The expected number of parts lost during the time interval from A to $(A+(Q/R))$, or the expected number of parts lost per lot due to obsolescence, is then the integral of Eq. 4. between the limits of zero and Q/R

$$\int_0^{Q/R} (B + Q - R\tau)\alpha e^{-\alpha\tau}d\tau = \left(B - \frac{R}{\alpha}\right)(1 - e^{-\alpha(Q/R)}) + Q \qquad \text{Eq. 5.}$$

The expected unit loss due to obsolescence becomes

$$E = \left(D + \frac{S}{Q}\right)\left(\frac{(B - R/\alpha)(1 - e^{-\alpha(Q/R)})}{Q} + 1\right). \qquad \text{Eq. 6.}$$

The total unit part cost C represented by the sum of the unit production cost P, the unit inventory cost I, and the expected unit obsolescence cost E, as given in Eq. 1., Eq. 2., and Eq. 6.

$$C = P + I + E = \left(D + \frac{S}{Q}\right)\left[2 + \left(B + \frac{Q}{2}\right)\frac{\beta}{R} + \frac{(B - R/\alpha)(1 - e^{-\alpha(Q/R)})}{Q}\right] \qquad \text{Eq. 7.}$$

Differentiating Eq. 7. with respect to Q and equating to zero, i.e. $dc/dQ = 0$, would yield an expression which, when solved for Q, would give the economic lot size. However, the derivative is an expression of third order in Q, and Q appears in the exponent of the exponential term. A computationally feasible expression for economic lot size results when the exponential term

$$e^{-\alpha(Q/R)}$$

in Eq. 7. is approximated by

$$e^{-\alpha(Q/R)} = 1 - \frac{\alpha Q}{R} + \frac{\alpha^2 Q^2}{2R^2} - \frac{\alpha^3 Q^3}{6R^3} \cdots \pm \frac{\alpha^n Q^n}{n!R^n}.$$

The sum of the series differs from the sum of the first N terms by less than the absolute value of the $(N+1)$st term, so when

$$e^{-\alpha(Q/R)} \simeq 1 - \frac{\alpha Q}{R} + \frac{\alpha^2 Q^2}{2R^2} \qquad \text{Eq. 8.}$$

the percent error is less than

$$\frac{\frac{\alpha^3 Q^3}{6R^3}}{e^{-\alpha(Q/R)}} \cdot 100.$$

Substituting Eq. 8. in Eq. 7.

$$C = \left(D + \frac{S}{Q}\right)\left\{2 + \left(B + \frac{Q}{2}\right)\frac{\beta}{2} + \frac{\left(B - \frac{R}{\alpha}\right)\left[1 - \left(1 - \frac{\alpha Q}{R} + \frac{\alpha^2 Q^2}{2R^2}\right)\right]}{Q}\right\}.$$

Now

$$\frac{dC}{dQ} = Q^2\left[\frac{D(\alpha+\beta)}{2R} - \frac{DB\alpha^2}{2R^2}\right] - S\left[1 + \frac{B}{R}(\alpha+\beta)\right]$$

and the economic lot size is

$$Q = \sqrt{\frac{2RS\left[1 + \frac{B}{R}(\alpha+\beta)\right]}{D\left((\alpha+\beta) - \frac{B\alpha^2}{R}\right)}}. \qquad \text{Eq. 9.}$$

Eq. 9. can be simplified by expressing buffer stock quantity B as a function of the annual requirement R, for example

$$B = yR \qquad \text{Eq. 10.}$$

and when Eq. 10. is substituted in Eq. 9.

$$Q = \sqrt{\frac{2RS[1 + y(\alpha+\beta)]}{D(\alpha+\beta-y\alpha^2)}}. \qquad \text{Eq. 11.}$$

For $y=0$ (i.e., buffer stock not considered), Eq. 11. becomes

$$Q = \sqrt{\frac{2RS}{D(\alpha+\beta)}} \qquad \text{Eq. 12.}$$

and if $X=\alpha=0$ (neither buffer stock nor obsolescence are considered), Eq. 12. reduces to

$$Q = \sqrt{\frac{2RS}{D\beta}} \qquad \text{Eq. 13.}$$

the classical economic lot size equation.

SUMMARY

The significance of obsolescence in economic lot size determination is readily seen in Eq. 12.

$$Q = \sqrt{\frac{2RS}{D(\alpha+\beta)}}.$$

The obsolescence rate α is seen to be directly additive to the annual inventory charge rate β, becoming an added deterrent to large lot sizes. For example, let $\sqrt{RS/D}$ be constant and with $\beta=.10$, and $\alpha=.40$ (expected part life span of 2.5 years), the economic lot size is reduced to less than 50% of the value obtained in the classical formula. Thus obsolescence can be a significant and potentially dominant factor in economic lot size determination.

The solution presented is for the particular case of an exponential part life distribution. However, the general method developed could be used with other life span distributions, e.g. Erlang.

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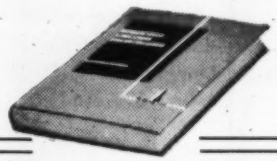

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Competitive Management Simulation

by CLIFFORD J. CRAFT

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HOW to get its share of the available executive talent is a serious problem for any company, particularly in an expanding economy in which the number of managerial jobs is constantly multiplying. Simply to hire needed talent away from another company is no solution when the total supply is—as it seems to be—growing less rapidly than the total demand.

So a number of American companies, particularly the large organizations that need talent in large quantities, are trying to develop their own. This is one reason for the striking growth of executive development programs over the last ten years or so. More than half of the 460 companies surveyed on this subject by the American Management Association in 1954-55 had some systematic plan, program, or method to facilitate the development of people in or for management responsibilities. In 1946, in contrast, only 5.2 per cent of 3,498 companies surveyed by the National Industrial Conference Board had executive training programs. The results of these two studies are not strictly comparable; the AMA sample included a higher proportion of companies likely to have such programs. But they do offer some statistical evidence of a trend already noted by many observers of the management scene.

Business leaders have always been trained in some way. Even the tycoons of the old "intuitive" school of management did not appear on the scene spontaneously. But the formalized approach to executive development came in with the organization man. It is still a relatively new concept. As a result, we still know a lot less than what we should know about teaching a man how to manage a corporation—or even just a part of it.

Most present-day executive development programs provide two types of training: education in facts and ideas, and training in management skills through practice on the job. The first type includes such relatively formalized activities as courses taught on company premises; sponsorship of participation in courses, seminars, and other educational meetings conducted by universities and associations; and company discussion groups for management personnel. These have the weakness that the information is transmitted only intellectually. The trainee does not "live" the situation, and the knowledge acquired does not become part of his habit patterns. The second type is illustrated by job rotation, junior management committees, and on-the-job coaching. This training does succeed in conveying skills but usually only in a narrow area. For example, an executive understudy usually cannot be allowed to live the job of the president, lest the company not survive the experience.

SIMULATION IN TRAINING

A new training device called stimulation or (more popularly) management gaming seeks to combine the merits of both types of development programs—to impart the broad company view now usually taught in lectures but to impart it as a skill rather than as an intellectual concept. Management simulation is a technique for letting the trainee, who may be a junior executive, a specialist, or even a president, actually run an artificial company or some portion of it, usually in competition with others. To make this feasible, game designers have borrowed from another field in which businessmen have been evincing growing interest, the idea of scientific simulation—usually by means of a mathematical model—of a business situation.

The first practical business game, a competitive general management game called Top Management Decision Simulation, was developed two years ago by the American Management Association. AMA now is using several different games as training techniques in some of its seminars and courses for business executives. These programs, which are intended to increase executives' competence in making business decisions, also include lectures and discussion sessions on such topics as organization, planning, review and appraisal, and decision making. But these principles are brought to life by a series of "simulation exercises."

Many companies and universities also have developed similar exercises and have incorporated them into their various training programs. Recent conferences on business games and management simulation (e.g., the University of Kansas meeting last December and the AIIE Second Systems Simulation Symposium last February)

have affirmed the important educational value of gaming. All indications are that the use of simulation exercises and games in executive training programs will increase substantially in the next few years.

Many refinements have been introduced into management gaming since Top Management Decision Simulation was introduced. However, it remains sufficiently typical to illustrate most of the advantages and disadvantages of the technique. We shall, therefore, use it as an example and describe it in some detail.

AMA SIMULATION EXERCISE

The AMA top management simulation exercise was based on a mathematical model of the business world. This model consisted of a group of cause-and-effect formulas or mathematical equations that determined the interaction of the decisions made by each competitor in the exercise. The results were calculated by an electronic computer, which contained in its "memory" the formulas of the model and thus was equipped to act as scorekeeper.

Participants in the exercise were divided into up to five teams or "companies." All companies were assumed to be manufacturing, in direct competition with each other, one identical product in the five to ten-dollar price range. At the beginning of the exercise, each company had exactly the same share of the market, exactly the same dollar value of assets, and exactly the same range of choices available.

The teams were given a fixed amount of time, initially about forty-five minutes, to organize their companies, plan their strategies, and select their decisions for the first period of the exercise, which represented three months or a quarter of a year in terms of the real business world. They elected officers, drew up organization charts, and prepared job descriptions for the functions involved—unless they decided to choose some other form of management such as a committee. They set their companies' business policies and objectives, spelling them out in writing, and set up annual and long range budgets for their firms. Then, from a list of specified alternative amounts, each company decided what price it would charge for the product during the quarter and how much it would spend for production, marketing effort, research and development, and additional plant investment.

CYCLE OF STEPS IN AMA EXERCISE

The companies indicated their operating decisions by circling them on a form, distributed to them at the start, which showed how much money each team had and on what it could be spent. When the choices had been made, the forms were collected and the decisions were key punched on cards for processing by the computer. Using the formulas in its memory, an IBM 650 computer calculated for each company the effects of its own and its competitors' decisions on the company's financial and operating position. Five minutes later each team received a new balance sheet and income statement, printed by an IBM 407 printer, showing how much of the product the company sold during the quarter and what its costs and profits were.

The companies were given about fifteen minutes to review their results, see how well they did during the quarter, try to guess what happened to their competitors and what the latter were going to do next, and revise their own tactics accordingly. Then, they circled their new decisions for the next quarter. This cycle was repeated quarter by quarter until the equivalent of several business years had elapsed. In a few days' time the exercise could simulate ten years of business operation. After the end of the exercise, the participants met in a "critique" session to get a look at their competitors' results, compare notes on strategies, and analyze where they went wrong and why.

ROLE OF THE COMPUTER

The complexities of the decision-making process in the AMA simulation exercise arose naturally out of the multi-sided, multi-stage nature of the simulation. The model itself was mathematically a simple one. It did not really require an electronic computer as scorekeeper. In the early stages of the development of the simulation model, the results of the participants' decisions were calculated by the research group on desk calculators. Computations for a single period took about 45 minutes. Performing these computations on a computer enabled the AMA research group to make the simulation exercise more realistic for both participants and staff without increasing—in fact, reducing—the total computation time. The total processing cycle—of key punching, computing, and printing—took less than five minutes on the 650. Using a computer, a wide variety of mathematical and clerical services could be performed for the participants, freeing them to concentrate on actual decision making. Also, the results of decisions were available almost instantly, a factor of considerable psychological value in any training situation.

Only the basic IBM 650 computer system was utilized in the AMA simulation exercise. The only memory unit employed was the magnetic drum. Information was read into and out of the computer on punched cards. The output cards were translated into report form by an IBM 407 printer. Before the exercise began approximately 1500 machine instructions, which the computer executed during the exercise, were loaded onto the magnetic drum from punched cards.

The computer used was a self-checking machine. When an error was made, the machine stopped and an indicator lit on the control console. Since the machine never could make an undetected error, no checks needed to be built into its instructions. It was programmed, however, with several checks to guard against input errors. When the teams' decisions were inserted into the computer, it added up each company's expenditures and compared the total

with the total funds that the company had on hand. If a team spent more than its available working cash, computations were halted, and the company was notified that it must make a new set of allocations. A similar check could have been used to prevent a company from deciding to produce more units of product than was possible with its existing plant capacity. Instead, the computer was instructed simply to list as decision alternatives on the quarterly report form only those manufacturing levels that were feasible.

The availability of an electronic computer was of great value in the development of the simulation model. The effect of slight changes in the mathematical model could be determined more rapidly and more easily than by hand calculations. Further, its use in the simulation exercise provided the advantages of clear, concise, error-free reports of results, simplicity of play for participants, and speed in evaluating decisions. The computer also permitted a more realistic model, more combinations of reports, and more data collection for analysis.

GAME THEORY, OPERATIONS RESEARCH AND SIMULATION

Management simulation is an outgrowth of game theory, the mathematical solution of the strategic and tactical problems found in such games as bridge, poker, dice, and football, and of such related analytical techniques as system simulation. Under such names as operations research, operations analysis, management science, or management research and synthesis, this whole complex of mathematical techniques is now being applied to the solution of business problems in many large companies. The underlying assumption is that a business problem can be solved in much the same way a scientist solves a problem in a laboratory, that is, by setting up a series of tests and then determining by experimentation or by straightforward mathematical analysis which of several possible solutions is the best or optimum.

To solve specific types of business problems, special mathematical theories have been developed. Linear programming is a mathematical method developed to maximize or optimize the scheduling of activities and the allocation of resources in cases where the return may be assumed to be directly proportional to the effort expended. Dynamic programming is a more sophisticated mathematical technique used to treat problems involving a sequence of decisions in cases where the various factors involved are not simply proportional as in the linear programming case. There are business problems that, because of the large number of variables involved, defy mathematical solution, even with a computer to perform the tedious calculations involved. To deal with them business researchers have turned to game theory and its corollary, simulation. Simulation involves the development of a model, usually mathematical, sometimes physical, and sometimes even a combination of the two. Physical models, like the wind tunnel and the Link trainer, simulate the problem of the airplane or its controls under flight conditions. The armed forces use both mathematics and visual and electrical devices to simulate a war, with all the noise, pressure, and other elements of a combat situation that can be reproduced artificially. Sometimes the simulation is of an analogous situation rather than the actual problem. Monte Carlo theory, for example, relates a simple process like throwing dice to the solution of a business problem like production scheduling.

In all these cases the model represents a microcosm of the reality. A system is simulated where the problem is one of man versus environment—in business, where man, machines, and facilities are pitted against an environment of uncertainty. Where, as in most business problems, the situation is that of man versus man or of man versus man and the environment, a somewhat more complicated technique may be used, that of competitive simulation. The AMA simulation exercise was an example of competitive simulation. Mathematically speaking, it was a multiphased, multi-sided simulation exercise.

BENEFITS TO THE PARTICIPANTS

As a training device, the simulation exercise was designed to give the executive intensive practice in the analytical techniques of decision making—in the process of selecting from a mass of available facts those that are pertinent to the problem he must solve, analyzing their meaning for the future, and deciding on an appropriate course of action. It also demonstrated vividly, to those executives who normally do not make decisions involving the company as a whole, how the top man must balance a myriad of competing and interrelated factors in guiding the operations of his firm.

The chief contribution of top management decision simulation to executive training was in the actual experience gained in decision making, together with the rapid reporting of results. An executive's highly intense "life" in the simulated business world increased his understanding of the decision process and sharpened his skills in: 1. collecting, evaluating, and analyzing data; 2. diagnosing situations; and 3. developing alternative solutions. However, the experience itself was not enough. Reflection, interpretation, and discussion were needed to crystallize it.

In group critique sessions after the end of a simulation exercise, participants reviewed the results of the exercise and compared data on critical events. They explained their own strategies, considered where they failed and why, and criticized each others' results. The process of filling in informational gaps, sharing experiences with other teams, and focusing upon the critical periods in which mistakes and successes occurred was designed to build in each participant an increased awareness of the role of planning and reviewing in business decision making as well as to develop some skill in the use of these management tools.

SIMULATION COURSES

In some of the courses now being conducted by AMA at Saranac Lake the key aspects of decision making are covered experientially in the simulation exercises, highlighted in critique discussions, enlarged upon in project sessions, and related to the larger context of business reality by guests lecturers. The phases of business management covered in the course curriculums include such important topics as:

1. The collection and objective evaluation and analysis of information.
2. The synthesizing of tentative decision alternatives.
3. The implementation of decisions through operations planning and review.
4. The proper organization for decision making.
5. The contributions to decision making of statistical analysis and operations research.
6. Minimizing the area of uncertainty.
7. The limiting factors inherent in the sequential nature of business decision making.
8. The importance of functional balance and internal coordination in business decision making.
9. Dealing with the necessity of commitment in the face of uncertainty.
10. Gaining acceptance and support of the decision by the working organization.

As a training tool management simulation is unique in the realism with which it reproduces business decision-making situations and in the intensity of the participants' emotional involvement. One of the graduates of the first course in which this technique was used, an executive vice president of a large manufacturer, commented, "There is no substitute for on-the-job training, particularly in top management positions, and this course is the closest I have yet seen to such training in a nearly real-life business situation."

Everyone who attended that first course took the simulated exercises very seriously. They put in long hours, frequently ignoring the scheduled break periods. On an average, at least a third of them worked straight through the recreation hours, poring over reports, plotting graphs, planning their next moves. Sometimes they were still in the simulation exercise rooms as late as one o'clock in the morning. One Sunday three executives came to work for their simulated "company" between church and lunch. Another executive pointed out, "You don't need to look at their badges to identify the men taking the decision-making course. They always look so intense, act as if they had nothing on their minds but business." Two members of one team almost came to blows over the company's strategy and had to be stopped by their "president."

Competitive spirit was strong. One group put a lot of effort into analytical studies of the market during the first simulation exercise in their course, a two-year run which was largely for orientation in the mechanics of the exercise. At the critique session they refused to share their strategy and the results of their research with the others, arguing that they might want to use it in the next exercise.

Although no direct contact between teams was permitted while the exercise was actually going on, members of teams who were doing well were unmerciful in their "heckling" of the less successful. One such company of hecklers, whose strategy left them unprepared for a sudden recession in the market, saw their assets decline by $375,000 in one quarter. Their next-door neighbors, whose own results were showing steady improvement, draped a wreath of carbon paper on the door of the "sick" company. The members of another team were so pleased with their balance sheet that they distributed green savings stamps to the AMA staff, who, incidentally, returned them when the company's fortunes changed.

TYPICAL REACTIONS OF PARTICIPANTS

Top management simulation also appeared to be effective in its objective of teaching executives the importance of good organization structure, coordination, and long range planning. One week after he returned to his company from a simulation course, the general manager of a subsidiary of a large company inaugurated his organization's first formal forecasting program. As a result of this action, his company's expected future sales and profits will be forecast monthly for the next three months, for the next year, and for the next five years. The chief executive of another company reports that he has formed his first formal management committee as a result of his experience in the decision-making course. He also is trying to define the various functions in his organization more clearly, to put more emphasis on formal training for his staff, and to accelerate and revise a recently launched executive development program.

These ideas are not new to industry, of course, and usually not even new to the men who take them home from a simulation course. Said one participant recently, "I had known these things in theory for years, but I never really felt them before." Said another, "The course makes you realize you've got to start now to apply some of these ideas you've been toying with for years—or you may not survive. Simulation is an alerting type of course."

Some have absorbed from the simulation exercise a new realization of the importance of specific operating factors they may have been neglecting in their own jobs. A financial executive in a non-manufacturing firm was particularly impressed by the effect of research and development in the simulation exercises and began trying to persuade his management to put more emphasis on research and development. A treasurer was impressed by the market research tools used in the simulation exercise and adapted them for his own use. A president who took part in one of the tests of the AMA model realized, after watching marketing expenditures at work in the simulation, that a new product his company was launching possibly had not been given a big enough advertising budget —so he upped it. A manager of a large railroad put it this

way, "One benefit relates to flexibility of thinking. I suspect that there may be quite a few participants who come to a simulation course with pretty fixed ideas as to the proper ratio of marketing or R & D expense to sales based on the traditions of their own companies or industries, but who go away with at least a little question in their minds as to whether some other ratios might not produce greater net income."

The course also seemed to have some psychological effect—for example, in increasing objectivity and self-confidence. Said an executive vice president of a large electrical manufacturing company, "It has stimulated me to have more information about our competition and our own market position." The treasurer and assistant general manager of a steel and wire company put it this way: "Today I find myself aiming at the key facts and sorting them with more purpose than in the past." He added, "The concentrated training, with open and frank analysis of results, gave me one additional advantage, more self-confidence." The executive of the large electrical manufacturer agreed, "Having been through a simulation course enables one to approach real life situations with just that much greater degree of confidence." One vice president, according to the president of his company, was a capable executive before his simulation experience, but had a tendency to be indecisive and retiring. As vice president of the simulated company, he wanted to raise the price of the product but was easily overruled. Finally, as the simulated company's affairs went from bad to worse, he exploded and insisted on a price-raising strategy. It worked. Back in his own company, he was a changed man, his president said. He was more aggressive than ever before, argued in favor of the same price-raising strategy, and won. It worked that time, too.

GENERALISTS VERSUS SPECIALISTS

One of the chief effects of general management simulation exercises—at least the one most frequently mentioned by the participants—is the orientation provided in the "big picture" of the company. Training people to think of their own actions and efforts in terms of the corporation as a whole is a problem at all levels of management, from the president who still leans toward the department through which he rose, to the production foreman who is hardly aware of the existence of the sales organization. But the higher an executive goes in the company, the more he is required to think about the relationship of one function to another and how the job of his department is going to improve the over-all enterprise.

In a simulation exercise managers have an opportunity to play—almost to live for a while—the roles of executives in other specialties. The financial man learns through simulated experience that you have to spend money to make money; the marketing man realizes that research and development may have as great an effect on the salability of the product as an elaborate advertising campaign. One company president, whose own background was largely military, was also elected president of his simulated company and spent all his time mediating among production, sales, and finance. He said the experience showed him that not only he, himself, but many others as well, lacked the whole picture of a company. He suggested—a remark echoed almost unanimously by the others—that top management decision simulation may be of greatest value to men of specialized background or function. Along this line, the executive vice president of a large manufacturer quoted above said: "A top management simulation exercise course experience would be tremendously beneficial not only to our neophyte and semi-experienced division managers and their assistants but also to our topmost line and staff personnel, whose progress has been via a highly specialized route—engineering, manufacturing, marketing, or finance."

CRITICAL REACTIONS

Most of the criticisms voiced by participants in early simulation exercises dealt with the details of the particular model used. Some of these criticisms were certainly valid, and the models were changed accordingly. In response to the others the practitioners in the field simply pointed out that any simulation model represents a compromise among conflicting objectives.

A common complaint was that the models were not sensitive enough to price changes. The size of the total market in an early AMA model, for example, represented the environmental factor in the man versus man and environment equation and was determined independently of the actions of the companies. The participants' decisions to raise or lower price would affect only their share of the market—not the market itself. If all the companies moved their prices in the same direction, which was a long-run tendency in the exercise, the effect on sales was negligible. The fact that the original model contained a total market that was increasing steadily at the rate of one per cent per quarter tended to penalize price-cutters and reward price-hikers to possibly an unrealistic degree. This continual prosperity was not realistic, executives pointed out; there should be an occasional depression or at least a recession. Since the formula for total market was withheld from the players, the research group felt that the actual nature of the market would not affect the companies' strategies—the participants still would have to make decisions on the assumption that a recession was possible. Subsequently, however, the AMA staff decided that a fluctuating market would make the exercise more interesting, and the model was adjusted accordingly.

Some executives also felt that the original model did not provide enough penalty for the poor control of inventory. Unsold inventory was added to total assets at the current cost of production. One acute executive brought his company in far in the lead on total assets at the end of the exercise by running full blast on produc-

tion in the final periods. The surplus inventory, which would have been disastrous in the real business world, counted as assets and swelled their final net. At his suggestion, the model was revised to include a five per cent inventory depreciation factor emphasizing that inventory is not the same as other more fixed assets.

This problem of the end effect still plagues all simulation exercises despite the steps taken to mitigate it. One possibility is not to tell the participants how many quarters the exercise will run; this approach has been tested several times and appears to be a practical solution to the problem.

A recurring complaint was that not enough time was given for decision-making. However, most participants disagreed and regarded the time pressure as advantageous or even occasionally asked for more compression. Some executives who like to maintain charts and other analyses of market and competitive trends said they did not have enough time to do a good job of it. To overcome this problem AMA's response was to give more aid in charting by providing forms and tools. Time compression was regarded as an essential feature of the simulation model, both because it helped to maintain participants' interest and, more important, because it kept them from fighting the model instead of the total business situation.

As in any simulation model, many aspects of reality were omitted from the model, and most of these omissions were criticized by participants at one time or another. Tax considerations were not a strategic factor in the exercise, for example. The companies did pay taxes; 50 per cent was automatically deducted from the increase in total assets each quarter for this purpose. But taxes were introduced into the model as a device to control cash flow, not as a variable; no decision by the company could improve or worsen its tax position.

Participants also complained about the rule against borrowing; all expenditures had to come out of cash. They asked for permission to borrow to improve their cash position; some recommended a dividend payout requirement to reduce cash flow and make money management a more realistic feature. In view of the current popularity of diversification as a management strategy in the business world, some participants suggested that mergers be added to the model to increase realism.

The general reply to all these criticisms was that a simulation exercise is only a training device—not an analytical tool. Any model is an abstraction of reality, not the reality itself. The addition of still more variables would have enormously complicated the mathematical and computational problems involved without necessarily adding to the training value of the simulation exercise.

An issue that was more upsetting to mathematicians than to business men was the absence of a specific criterion for winning the game. Game theory, the mathematicians pointed out, has been designed for the case where a definite quantitative payoff function is defined and expresses the outcome. If no definite payoff function is given, it has to be constructed before the theory can be applied successfully. However, the AMA model was constructed largely without the aid of game theory because of the latter's limitations where multi-sided games are involved. The model was outside game theory in the sense that formulas cannot be derived mathematically by observation of the results. The real answer to the criterion objection, however, was realism. In the real world there is no generally accepted measure of business success; executives who took part in the simulation exercises were fully aware of that fact and seemed quite undisturbed by having to set their own goals.

FUNDAMENTAL ISSUES

More basic questions about the technique of simulation remain largely unanswered and may not be answered for a long time. There is ample evidence that a simulation exercise is effective as a teaching device. But does it teach the right thing? Some of the things it teaches—or seems to teach—are right, in the view of most executives who have participated in a simulation exercise. The analytical approach to decision making, the importance of planning, the value of facts, the necessity of keeping operations in balance—these are things every executive must learn and learn well. But the actions that bring success in the business world of the model should not be learned because they are not facts of life in the real world.

Is there any danger that participants will try to apply literally in their own companies the strategies that worked in the simulation? Will they assume, perhaps unconsciously, that the relationships that exist in the model among marketing, research and development, sales, and production also exist in their own industries? This would be disastrous, for those relationships are not valid in the specific real life for any individual person. The participants are told that many times, of course, but their experience in the exercise may tend to offset the effect of mere words. The danger of literally unevaluated carryover is inherent in any simulation, even in the study of a case history. The danger is probably intensified, however, in a simulation exercise because of the high level of emotional involvement that is one of its most striking characteristics.

Management simulation does seem to develop business decision makers, but does it develop the right kind of decision? The AMA model was loaded against extreme policies. In the effort to teach the manager to maintain the proper balance among the various aspects of business, it may have gone too far in discouraging daring innovation. Taking long chances has made fortunes in business but never in the AMA simulation. The principle of marginal change made it difficult for a company to adopt any really drastic policy. A policy of strong emphasis in one area, the equivalent of an all-out sales campaign or a major research and development effort, could be pursued,

though gradually, but it did not pay off handsomely in the AMA model. Both marketing and research and development expenditures were treated as non-linear functions; and after certain expenditures, the point of diminishing returns was reached. This may not necessarily be true in real business, where there are qualitative as well as quantitative factors.

Constants in the formulas protected even a "do-nothing" company from going completely broke; no policy, no matter how inept, could, at the outset, reduce a company's share of the market below a certain percentage, for example. The model was constructed that way because the exercise was a training tool; the player eliminated from a game gets no practice in playing it. But bankruptcy can be the outcome for a real company that does not keep up with new developments and is not alert to opportunities. Nor could a team make strikingly high profits in the exercise. The big fortunes in business are made by opening up a new market or by increasing the size of the old one, not by stealing customers from competitors. This was impossible in the AMA simulation because there was only one market and new products could not be introduced. Was not this conservative bias just another of a whole complex of factors in industrial society tending to produce the "organization man"?, some critics asked.

Perhaps so. But while it was impossible to earn a 200 or 300 per cent profit, many teams succeeded in reaching reasonable profit levels. The simulated companies started in a relatively poor position, earning only about 3 per cent on their investment, with production costs amounting to 80 per cent of sales income and with only about $10 million in cash. Some participants, on seeing the initial income statement, suggested that the best thing to do with this company was to burn it down and collect the insurance. But some teams in the simulation exercises succeeded in increasing return on investment to 18 or 20 per cent in a few "years" of play.

EXECUTIVE TESTING

Some psychologists and executives of companies that have sent representatives to simulation courses have expressed serious interest in the idea of using simulation exercises for executive testing. They have talked about sending candidates for promotion to decision-making simulation courses or setting up similar simulations in their own companies as a test for prospects—with the job going to the "winner." Most experts in the field, however, are quite skeptical. Although no formal studies have been made, experience to date with simulation exercises does not suggest any correlation between success in a particular simulation and success in the real business world—nor have any specific discriminating factors emerged. This is undoubtedly one of the most controversial uses of simulation. On the other hand, while there are many pitfalls standing in the way of this avenue of development, people are, in fact, being evaluated today by techniques equally crude; for example, the personal interview. Since simulation puts the participants under stress, careful psychological observation during an exercise might uncover some information about a man's reactions and ability to perform under pressure.

BUSINESS RESEARCH

Can management simulation be applied in business research? Could a detailed study of such a model in action teach one something about business that he could not find out otherwise? Most experts in the field think so, and regard business research as one of the chief potential uses of the technique.

Study of the AMA top management simulation probably would not yield any valuable insights into the theory of business enterprise. The model, while realistic enough for training purposes, was hardly realistic enough to serve as a tool of the economic world. Its business world was a highly stylized one. The value relationships among the resource factors were arbitrary ones, and many of the factors that do operate in the real world were intentionally omitted; for example, chance factors like weather and war and the more controllable business factors like taxes, borrowing, dividends, and mergers. Simulation in general, however, would seem to be an appropriate tool for economic analysis. Several economists are now working on a mathematical model simulating the input and output of capital in the American economy.

For the study of management and its techniques, and particularly for the study of the actions of businessmen themselves, simulation has real potentiality. Interest in management concepts and principles is growing among social psychologists, psychometricians, and other social scientists. They have been attempting to develop theories for the order of information flow, organization structure, communication, and decision, but nowhere is there a mechanism for deriving data applicable to such an analysis. This is the standard research problem of the social scientists—how to set up a laboratory experiment under the circumstances that most of the factors or variables can be held constant to permit analysis of a limited number of remaining variables. Exactly such an opportunity is offered by simulation models. Some use has already been made of simulation for purposes of management research. Simulation has been tried at Northwestern University to study the development of organizations. Case Institute has made small studies of communications and organizations. One leading psychologist feels that simulation has more potential as a management research tool than any other single scientific technique now available.

VALUE OF SIMULATION IN TRAINING

Practitioners in the simulation field have been particularly intrigued by the possibility of studying the teaching impact of simulation exercises by measuring how much,

if at all, they change a participant's attitudes on such business subjects as planning and organization. Preliminary studies by two psychologists and the Rand Corporation indicated that such research is feasible but costly.

Graduates of any simulation course seem to emerge sold on the concept of simulation and scientific techniques of decision making. The number who already are beginning to apply these ideas in their own companies attest to that.

To some, management simulation also looks like an ideal psychological laboratory for investigating how businessmen make decisions and what influences them. The behavior of executives participating in an exercise could be observed for the purpose of analyzing such questions as: 1. how much influence group feeling has on individual thinking, 2. what happens when facts and preconceived notions conflict, 3. how far competitive psychology will drive businessmen to hurt their competitors even at risk to their own interests, and 4. when and why managers are influenced to cut prices. Casual observation of the participants in the AMA top management simulation exercises raised some provocative questions about pricing, for example. Despite a team's freedom to set prices as they pleased (there was no monopoly, government regulation, fair trade, nor any possibility of price combinations), price leadership was characteristic in most cases. Does this mean that following the leader on price is a normal psychological reaction in business? Information of real scientific value could emerge from use of models as mirrors of business experience.

USE OF SIMULATION IN INDUSTRY

Interest in the practical use of system simulation in industry was already a growing trend in management and industrial research before the development of the AMA simulation exercise. The Westinghouse Electric Corporation had used simulation in plant scheduling and inventory distribution, and the General Electric Company in job shop scheduling. United Air Lines had a simulation model of operations at a large airport. Imperial Oil Limited had distribution and inventory control models. The Port of New York Authority simulated peak-hour bus operations; the Southern Pacific Railroad, freight car inventory and distribution; the Office of Naval Research, cargo handling; and there were many others.

But the AMA top management decision simulation has clearly given impetus to this trend. One executive in an early AMA test exercise returned to his company so enthusiastic about simulation that, at his suggestion, the firm is constructing a mathematical model of the company's operations and the industry for use in long range planning. Another participant was stirred by the possibilities of operations research as a result of his course attendance. In the division of which he is general manager, he found a man who had some OR training and assigned him as a consultant to help the division's quality control, sales, and particularly the manufacturing group develop a more scientific approach to their problems. Many others have adopted the idea of simulation as a training device.

NEW NONCOMPETITIVE GAME

Most management games which have been developed to date are competitive. Groups of players or teams simulated competing companies, and the objective of each team in an exercise was "to win" by, for example, amassing the largest total assets. A new type of noncompetitive game was jointly developed by the American Management Association and Remington Rand. It is known as integrated materials management simulation.

The research program leading to the development of this exercise was launched shortly after the American Management Association announced their first course using the AMA game. Mr. Franc Ricciardi and one of the authors met with Mr. Al N. Sears of Remington Rand, and an agreement was reached for American Management Association and Remington Rand to jointly develop this materials management game. The purpose of the exercise was to provide executive trainees with simulated experience as materials managers—a new industrial management concept. Specifically, this game was to be designed for the new AMA course on Integrated Materials Management. Once the project was launched, the actual mathematical and programming work was done by Mr. Joel M. Kibbee of AMA and by Mr. David McGalliard and Mr. Ed L. Fitzgerald of Remington Rand.

The following is a description of the most recent version of the materials management simulation exercise. It was extracted from a description of the game which can be obtained by writing to Mr. Andrew S. Lang in care of the American Management Association, Saranac Lake, New York.

In the materials management exercise, a team of executives is given the opportunity to manage the overall flow of materials from the purchasing of raw materials through inventory control and production scheduling up to the distribution of finished goods to field warehouses. The objective of the team (headed by a "materials manager") in this exercise is to manage the company's operations in such a way as to achieve the lowest total annual cost for the overall operation. This, obviously, includes the overall optimization of the conflicting classical objectives of inventory management (i.e., minimum levels of inventory), production management (i.e., leveled production), and marketing management (i.e., high inventory levels).

The integrated materials management exercise simulates the flow of materials in a manufacturing organization. The company has two plants, manufactures two products, and markets them in two regions. Several companies may be in operation at the same time, through joint use of the computer, but there is no interaction be-

tween them and each operates independently of the others. There is competition only insofar as each company, starting from the same conditions, attempts to achieve the best performance.

The objective of each company is to satisfy the sales demand at minimum cost through good materials management. The demand varies from month to month but is not known in advance by the participants—although a sales forecast is usually provided—nor does their action influence the demand. The sales price is fixed; a sales income and gross margin is shown to the participants at the end of each simulated period. The general objective is to maximize gross margin. Except insofar as stock outs represent lost revenue, gross margin is only increased by decreasing costs.

The simulated time period is months. The "new management" takes over at the beginning of January (Month 1), has at hand the performance report for December (Month 0), and it then proceeds to make decisions for January. These are fed to the computer, and a performance report for January is returned. Decisions are then made for February.

The exercise normally runs for 12 simulated months; the participants, however, must leave their companies in a sound position. It should be emphasized that while maximum accumulated gross margin is the general objective, it is not, of course, proof of good materials management.

CONCLUSIONS

Some of the reasons for the growing interest in management simulation are:

1. The high degree of realism which is possible in a management game, particularly in computerized games.
2. The amount of personal involvement and the intense personal motivation which it is generally possible to achieve even with relatively simple mathematical models.
3. The substantial compression of time which, in a typical instance, may approach one year of simulated operation per hour of actual play.
4. Games can be designed to teach almost any level of management or any area of specialization.

Manual, or noncomputer, games can be used very effectively in training and are quite inexpensive. While many games are very simple and do not include random factors in their model, these games are still nondeterministic from the players' points-of-view since the players generally are not given a perfect forecast.

Notwithstanding the many positive benefits of using simulation in training, games must be used with real caution. As anyone who has played a management game knows, a game can be a very traumatic experience to a person who is "losing," simply because the personal involvement is so great. Also, many of the classical safeguards of traditional teaching are lost (e.g., a student usually is cautioned not to believe all that a teacher says, or he does not anyway). Therefore, games should only be used as one part of an overall training program consisting of lectures, demonstrations, etc.

Some of the manual or noncomputer games described in the literature so far have been misleading. These articles have tended to over-simplify the problems of formulating the mathematical model. Simulation models and management games are such a pleasurable way to "spoon feed" executives such abstract concepts as "simulation" that management may conclude that games can be easily designed to accomplish any and all training objectives.

It is true that simulation, as a training device, is not for the Bernard Baruchs. But the real problem of business is not to train Baruchs—who probably do not need it anyway—but to develop managers who will understand their company and its problems as a whole and are capable of running a balanced operation. Instead of producing conformists, the simulation experience should, by encouraging attention to facts and improving skill in their use, make the executive more ready to see and seize an opportunity.

In any case, simulation does seem to be an excitingly effective training device. The complex problems of running a business are presented in a way that seems to facilitate rapid comprehension, active participation, and intense involvement in the processes of planning, review, and analysis. It seems almost certain to become a familiar training method in industry and in the universities. It may well be true that top management decision simulation was, as AMA claimed, a major breakthrough in management education.

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Linear Programming in the Packing Industry[1]

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ONE of the many important decisions that have to be made periodically in a manufacturing business is that of selecting a processing plan to make the best use of existing facilities and which will also result in a profit for the company. It would be extremely desirable if the decision resulted not only in a profit, but the maximum profit that could be realized. This is difficult to do using judgment or usual trial and error methods. However, linear programming provides a method of determining an optimum processing plan when there are many variables and many choices.

An optimum plan will be presented here for a meat packing plant taking into consideration such factors as the number of hogs to be processed, the weight of the hogs, the production costs and selling prices of the final products, production facilities available, etc. The Linear Programming plan developed here will serve as an example of how a processing plan can be selected for similar situations. It should be noted however that all data are estimated and based on one plant.

In this situation the manager of a small meat packing plant wishes to know what proportion of hams, bellies, and picnic hams should be processed for sale as smoked product, and what proportion should be sold fresh or green. This example concerns only these products. He is limited by the handling capacity of his plant and also by the use of existing equipment and facilities.

LINEAR PROGRAMMING ASSUMPTIONS AND LIMITATIONS

The Simplex Method for solution of linear programming problems which is used in this example is completely general. Any linear programming problems can be solved by this method. In the past few years, other simplified computational techniques have been developed for particular types of problems, some of which might have been used effectively in this example. The purpose of this example, however, is to show an application of linear programming as such to an industrial problem.

Before proceeding further, it is well to discuss the assumptions made and limitations of the linear programming technique. There are basically four assumptions. These are:

1. Linearity
2. Divisibility
3. Additivity
4. Finiteness

Linearity means that the ratio of output to input of any process is constant regardless of the level at which the process is being used. Thus if an input of 100 hogs to a meat packing plant results in an output of 200 hams, an input of 200 hogs will result in an output of 400 hams. This assumption neglects such delays as those caused by absenteeism, machine breakdown, worker fatigue, rejects by government inspectors, damaged meat, etc. However, these factors are usually known on some average basis and can be included in the calculations.

Linearity also assumes that it will cost twice as much to double production using the same process or processes and that sales revenue will double with a twofold increase in output. This assumption neglects increases in productivity or reduction of sales prices due to large quantities of a product being placed upon the market. The assumption of linearity is not a new one, since it is made in

[1] Authorized for publication as Purdue University Agricultural Experiment State Paper Number 1401.

nearly all production estimates and schedules, whatever method is used.

Divisibility means that any process may be operated at any positive level. For example, if 40,000 pounds of meat can be smoked in a smokeoven in 11 hours, it will be possible to smoke 29,091 pounds of meat in 8 hours. This is a definite restriction if used in this manner, since the smokeovens are usually loaded with a specific quantity of meat that stay in the ovens for a specified time. This can be taken care of by considering the smoking operation as a step in the productive process requiring a certain time for completion.

Additivity indicates that if there are two processes A and B that can be operated at levels X and Y respectively, the total output of the two processes is $X + Y$. This assumption give us very little difficulty.

Finiteness means that the number of productive processes available is finite. For most industries, this is not an unduly restrictive assumption. For some industries, such as agriculture, oil refining, and chemical industries, this assumption involves a greater degree of restriction.

PROCESSING PLAN ASSUMPTIONS

Certain factors must be assumed or otherwise accounted for in solving mathematical problems. This is also true, of course, in Linear Programming. For this example, the following assumptions are made:

1. The hogs received into the plant during one day are also processed during one day.
2. The ratio of input to output of any process remains constant regardless of the level at which the process is being operated. That is, if an input of one hog results in an output of 20 pounds of smoked hams for a given process, an input of 100 hogs will result in an output of 2,000 pounds of smoked hams for the same process.
3. The selling price of the final products in the example given are based on quotations from the Packers' Daily Record, a market quotation list published daily by James P. Lennon and Company, of Chicago, for the information of firms engaged in the livestock market.
4. The company is able to sell all of its output since it is operating in a completely elastic market. Regardless of the decision to smoke or to sell green any or all of his products, the market prices as reflected in the Packers' Daily Record will not be affected. This is not an unreasonable assumption if we assume that the output of this plant is small when compared to the total output of all meat packing plants. The decisions of really large meat packers and the demands of the consumer market would affect these prices, however.
5. All products are sold F.O.B. at the meat packing plant. Any differential in selling price from one area to another can be attributed to the difference in transportation of the products to that area.

Since the decision regarding the processing of hams, bellies, and picnics will have no effect upon the killing and dressing of a hog until these products are separated from the carcass, the steps can be neglected from the time that the hogs are brought into the plant, killed, and cleaned, and the carcasses chilled to the proper cutting temperature. At this point, the process becomes different for each of the separate products. The operations for each process can be listed as in Table 1. Thus, we have six distinct processes involved that are different in their operations and/or operation times. However, some work may have to be done during overtime periods, and although the operations and operation times remain the same for the products, the costs are higher for work done during overtime periods. In order to satisfy the assumption of linearity, that is to double production also doubles cost, we must consider the work done during overtime periods as different processes. As a result, we have nine processes to consider instead of six. Processing of green hams would not be done on overtime.

TABLE 1

Processes Chart

Product	Process for Smoked Product	Process for Green Product
Ham	1. Cut ham from side 2. Trim 3. Grade (weight) 4. Pump arteries with curing solution 5. Cure (in curing tanks) 6. Insert in stockinette 7. Smoke 8. Chill 9. Pack and ship	1. Cut ham from side 2. Trim 3. Grade (weight) 4. Freeze 5. Pack and ship
Bellies	1. Cut belly from side 2. Trim 3. Skin 4. Grade 5. Pump with cure 6. Smoke 7. Chill 8. Pack and ship	1. Cut belly from side 2. Trim 3. Grade 4. Freeze 5. Pack and ship
Picnics	1. Cut picnic from side 2. Trim 3. Grade 4. Pump with cure 5. Smoke 6. Chill 7. Pack and ship	1. Cut picnic from side 2. Trim 3. Grade 4. Freeze 5. Pack and ship

The factors that will influence the manager's decision are listed here and will be taken into consideration in this sample problem.

1. Input of hogs to the plant.
2. Weight of the hogs.
3. Proportion of input weight expected to be available for processing as hams, bellies, or picnics.
4. Flow quantity through the most restrictive operation in each process before overtime work is necessary.
5. Production costs per unit of output for each of the processes involved.
6. Selling prices of final products.

Based upon past records, the average input is about 2,000 hogs per day. Therefore 1,800, 2,000 and 2,200 hogs per day are considered as three typical input levels.

Also from past records, we find that the majority of the hogs received can be classified into three weight categories: 180-220 pounds, 220-260 pounds, and 260-300

TABLE 2

Proportion of Weight of Product to Live Weight of Hog—Percent

Product	200 lb. live wt.	240 lb. live wt.	280 lb. live wt.
Hams	12.00	11.75	11.50
Bellies	10.00	10.50	11.00
Picnics	5.75	5.50	5.25

pounds. So 200, 240, and 280 pounds are therefore considered as three likely average weights of hogs.

A sample of hogs from each weight was selected to determine the proportion of hams, bellies, and picnics to be expected for each input of hogs of a given weight. This was done by taking a number of hogs from each of the three weight classes and measuring the weights of hams, bellies, and picnics that are cut from the carcass. The results are summarized in Table 2.

It is also necessary to determine the weight of the final smoked product when compared with the green weight as cut from the carcass. There is a certain amount of increase in weight due to the addition of a curing solution, and a decrease due to shrinkage while in the smokehouse. The results are summariezd in Table 3. Note that the

TABLE 3

Ratio of Smoked Weight to Green Weight—Percent

Product	200 lbs.		240 lbs.		280 lbs.	
	Product	Scrap	Product	Scrap	Product	Scrap
Hams	100.0	2.2	100.0	2.2	100.0	2.2
Bellies	88.1	2.3	88.1	2.3	92.9	2.9
Picnics	100.0	—	100.0	—	100.0	—

total weight of smoked hams plus scrap is 102.2 percent of the green weight. This increase occurs as the cumulative effect of adding the curing solution and the smokehouse shrinkage. The scrap should be included since it represents a certain monetary value either as a salable item or as a raw material for another product. This monetary value can be deducted from the production costs of the respective processes.

The analysis of the processes revealed that the most critical operation for the processing of smoked products is the pumping operation. The restriction on this operation is shown in Table 4.

Also, for the inputs being considered, all of the products could be processed for sale fresh without requiring overtime work. This is shown in Table 5.

TABLE 4

Critical Flow Quantities in Hundreds of Pounds[2]

Average Hog Weight	Smoked Ham K_4	Total Bellies and Picnics K_5
200	106	315
240	113	397
280	116	484

[2] Flow quantity weight through the most limiting processing operation before overtime work is necessary on any given day.

TABLE 5

Total Weight of Fresh Product Available for Processing

Hog Input	Average Hog Weight	Total Fresh Product Weight in Hundreds of Pounds		
		Hams, K_1	Bellies, K_2	Picnics, K_3
1800	200	432	360	207
1800	240	508	454	228
1800	280	580	554	265
2000	200	480	400	230
2000	240	564	504	264
2000	280	644	616	294
2200	200	528	440	253
2200	240	620	554	290
2200	280	708	678	323

It is well to note here that this or any other technique used to arrive at an optimum program is only as accurate as the data used. Cost data, especially, must represent as nearly as possible the actual costs involved. For example, it would not be desirable to use the same unit cost for removing hams from the carcasses as is used for removing picnics from the carcasses. Only by setting up cost records so as to effectively pin down all costs accurately for a process, will these techniques provide a reliable basis for decision. All the costs that can be directly charged to the product such as labor, packaging materials, fuel for smokeovens, electricity for freezing rooms, storage charges, etc. are shown in Table 6. They should have subtracted from them the credit for scrap and trimmings. The results will then be the actual production costs for the different processes.

TABLE 6

Processing Costs in Cents per Pound of Final Product[3]

Product	Average Hog Weight-lbs.	Smoked Product (Regular Time)	Smoked Product (Over Time)	Green Product
Hams	200	5.18	6.58	.50
	240	5.18	6.58	.50
	280	5.18	6.58	.50
Bellies	200	4.76	5.54	.48
	240	4.76	5.54	.48
	280	4.47	5.26	.48
Picnics	200	5.62	6.92	.51
	240	5.62	6.92	.51
	280	5.62	6.92	.51

PREPARATION OF THE PROBLEM

Now with all of the necessary data for the solution of

[3] These costs are also in dollars per hundred pounds of final product. The costs include credit for scrap (ham hocks, fat trimmings, skins, etc.) and are corrected for differences between smoked and green weights due to shrinkage, etc. The above costs are not to be construed as the costs involved in any actual situation but rather are presented here for use only in the sample solution.

the problem compiled, the linear programming technique can be applied and the optimum program determined. A brief mathematical discussion wil be given first, followed by the procedure for construction of the sample problem.

The amount of any product to be processed will be designated as X_1 in hundred pounds and the total production of the nine processes as:

$$\sum_{i=1}^{9} X_i$$

where X_i is in hundreds of pounds, and

X_1 = weight of hams to be smoked during regular time
X_2 = weight of hams to be smoked during overtime
X_3 = weight of hams to be sold green
X_4 = weight of bellies to be smoked during regular time
X_5 = weight of bellies to be smoked during overtime
X_6 = weight of bellies to be sold green
X_7 = weight of picnics to be smoked during regular time
X_8 = weight of picnics to be smoked during overtime
X_9 = weight of picnics to be sold green

Also let

K_1 = total green weight input of hams
K_2 = total green weight input of bellies
K_3 = total green weight input of picnics
K_4 = limiting flow quantity for smoked hams
K_5 = limiting flow quantity for the total smoked bellies and picnics

The total revenue from the sale of these products will be denoted as

$$\sum_{i=1}^{9} X_i S_i$$

where S_i denotes the selling price of X_i in dollars per hundred pounds.

The total production costs for these products will be denoted as:

$$\sum_{i=1}^{9} X_i C_i$$

where C_1 is the cost of producing 100 pounds of product X_i.

The total profit from the sale of the products is the amount of product sold times the difference between the selling prices and costs. For any given product,

$$P_i = X_i(S_i - C_i).$$

Thus the total profit from the sale of all products is

$$\sum_{i=1}^{9} X_i(S_i - C_i)$$

or simply

$$\sum_{i=1}^{9} P_i.$$

The problem can now be stated as:

$$\sum_{i=1}^{9} P_i = \text{maximum}$$

in other words, it is desired to maximize the total profit from the sale of hams, bellies, and picnics. However, there are several limiting restrictions that must be considered.

Since negative production is not possible all processes must be operated at non-negative level. Therefore, the input to any process must be equal to or greater than zero (≥ 0).

$$X_i \geq 0.$$

Also, the sum of the input weights to the three ham processes must equal the total input weight to all processes.

$$\sum_{i=1}^{3} X_i = K_1.$$

A similar restriction applies to bellies

$$\sum_{i=4}^{6} X_i = K_2.$$

Also for picnics

$$\sum_{i=7}^{9} X_i = K_3.$$

The amount of smoked products to be produced during regular time (X_1, X_4, and X_7) are limited by the flow quantities for the critical operations. Therefore X_1 cannot be larger than K_4 and the sum of X_4 and X_7 cannot be larger than K_5.

$$X_1 \leq K_4$$
$$X_4 + X_7 \leq K_5.$$

It is now possible to determine the optimum program for one of the combinations of hog input and average hog weight. Consider the particular situation where there is an input of 2,000 hogs per day with an average weight of 200 pounds.

TABLE 7

$X_1 + X_2 + X_3 = 480$
$X_4 + X_5 + X_6 = 400$
$X_7 + X_8 + X_9 = 230$
$X_1 \leq 106$
$X_4 + X_7 \leq 315$

TABLE 8

Initial Construction of the Problem

Row No. \ Column No.	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q
1				1.32*	−.08	0	.72	−.06	0	.89	−.41	0	−10.00	−10.00	−10.00	0	0
2			Q	H_{sr}	H_{so}	H_g	B_{sr}	B_{so}	B_g	P_{sr}	P_{so}	P_g	A	B	C	D	E
3			480	1	1	1							1				
4			400				1	1	1					1			
5			230							1	1	1			1		
6			106	1												1	
7			315				1			1							1
8																	
9																	

* Profits.

To restate the restrictions:

$$\sum_{i=1}^{3} X_i = K_1$$

$$\sum_{i=4}^{6} X_i = K_2$$

$$\sum_{i=7}^{9} X_i = K_3$$

$$X_1 \leq K_5$$

$$X_4 + X_7 \leq K_5.$$

The values for K_1, K_2, and K_3 can be obtained from Table 5 and values for K_4 and K_5 can be obtained from Table 4.

The restrictions can be expanded and the values for K_1, K_2, K_3, K_4, and K_5 added.

Assume that the difference between the selling prices for smoked and green hams is **$6.00** per hundred pounds, between smoked and green bellies **$5.00**, and between smoked and green picnics **$6.00**. The selling price of the smoked product is the higher of the two prices.

The profit from the sale of each of these products can also be determined. Actually, the relative profit between the sale of smoked product and the sale of green product is all that is necessary. If the difference in selling price of smoked product over green product is greater than the difference in production costs of smoked product over green product, it will be more profitable, of course, to process and sell the smoked product. Thus only the differences between costs for smoked and green products need be considered.

For each process, the relative profit is determined. For this example, these profits are listed below.

Profit = difference in selling price minus difference in production cost.

P_1 = $6.00—($5.18—$0.50) = $1.32
P_2 = $6.00—($6.58—$0.50) = —$0.08
P_3 = $0.00
P_4 = $5.00—($4.76—$0.48) = $0.72
P_5 = $5.00—($5.54—$0.48) = —$0.06
P_6 = $0.00

INITIAL CONSTRUCTION OF THE PROBLEM

With this necessary information obtained, the problem is set up in the form of a tableau or matrix using the following mnemonic designations. This box-like arrangement is shown in Table 8, "Initial Construction of the Problem."

H_{sr} = the hams to be smoked during regular time (X_1)
H_{so} = the amount of hams to be smoked during overtime (X_2)
H_g = the amount of hams to be sold green (X_3)
B_{sr} = the bellies to be smoked during regular time (X_4)
B_{so} = the bellies to be smoked during overtime (X_5)
B_g = the bellies to be sold green (X_6)
P_{sr} = the picnics to be smoked during regular time (X_7)
P_{so} = the picnics to be smoked during overtime (X_8)
P_g = the picnics to be sold green (X_9)

1. Place these symbols in row 2 starting with the fourth column d. In row 1 above these products, place their associated profits.
2. Take the first restriction and place the coefficients of the variables under their respective headings in the row immediately under the product symbols. For the first restriction in this problem, X_1, X_2, and X_3 all have coefficients of 1. Place a 1 in Row 3 under the headings in the boxes associated with the coefficients. Place the constant also in the same row, but under the column heading Q in column c.
3. Repeat for all other restrictions as shown in Row 4, 5, 6, 7. The vertical lines in Table 8 are considered as plus signs and the double vertical line as an equal sign. Note that the restriction equations are arranged in reverse order to those shown in Table 7.
4. Notice that some of the restrictions in Table 7 are expressed

as equalities or equations and others are expressed as inequalities or inequations. This can be taken care of in Table 8 by adding another variable to each restriction. The adding of another variable serves two purposes. First, it allows the handling of only one type of mathematical expression throughout, namely equations. This added variable in the case of an inequality is called a "slack variable" and in effect, makes the expression an equality. The added variable in the case of an expression that is already an equality is called an "artificial variable." The second purpose of these "slack" or "artificial variables" is to provide a starting point for the solution as will be shown later.

The next step then is to add these variables to the restrictions already in the matrix as shown in column m, n, o, p, and q. Note that each restriction has a different slack or artificial variable associated with it. A profit value is assigned to each of the variables and is placed in the square above it as with the variables H_{sr}, H_{so}, H_g, etc. The associated profit for a slack variable is zero, and for an artificial variable is a negative value that is considerably larger than the profits associated with any of the real variables. In this example, -10 has been assigned. This large negative profit will emphasize that it is important that the restriction with which it is associated is met. For example, in the first restriction, any hams not produced as H_{sr}, H_{so}, or H_g will show up as being processed by the artificial process A but with a large negative profit, indicating that it is costing us money not to process in some manner all of the input (K_1). For further discussion on slack and artificial variables, see Charnes, Cooper and Henderson (1).

SOLUTION OF THE PROBLEM

The next step in the procedure is to determine a feasible solution shown in Table 9, "First Feasible Solution." A solution will be considered as feasible if it meets the requirements of the restrictions with the added slack or artificial variables. The best and easiest solution to start with is one using only the slack or artificial variables. This, it will be recalled, was one of the purposes for the use of these variables. All other variables are zero in our first feasible solution. In other words, nothing is produced with this feasible solution. In the column b, headed V, the artificial variables corresponding to the row are placed, and to the left of the variable, the unit profit for that variable is inserted.

Intuitively, we know that this is not the best possible plan to use. However, this method provides a starting point for arriving at the optimum solution in a systematic manner always resulting in an increase in profits when proceeding from one feasible solution to another. Each subsequent solution will provide a more profitable plan until the optimum plan for the situation being considered is obtained.

The next step is to take the coefficients for each column and multiply them by the profit associated with the variable under V in the row that the coefficient occurs. Sum the products and enter them in the boxes in row 8 for T. For example, for the column H_{sr}, these products are 1×-10 and 1×0. The total is therefore -10, and that value is placed in the T row. This is also done for the Q column. For Q, the T value is 480×-10, plus 400×-10 plus 230×-10 or $-11{,}000$. This T value for column Q is the relative profit for this plan.

The next step is to find a better solution that also satisfies the restrictions. In order to do this, the product variable which will result in the greatest increase in the relative profit is determined. This is done by inspecting the values in the P-T row and selecting one with the highest positive value. In this case it is H_{sr}, with a P-T value of 11.32. For the column that has the highest positive value, each positive coefficient is divided into the Q value for the row represented by the coefficient. In this case 1 is divided in 480, and 1 into 106. The resulting value that is the smallest positive result designates which of the variables under V is going to be replaced with H_{sr} which in this case is, of course, D. Another matrix, Table 10, "Revised Program," is now set up. The manner in which the new coefficients are assigned is as follows:

1. Write the equation for the columns using the double line as

TABLE 9

First Feasible Solution

Row No.	Column No. a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q
1	P			1.32	−.08	0	.72	−.06	0	.89	−.41	0	−10.00	−10.00	−10.00	0	0
2		V	Q	H_{sr}	H_{so}	H_g	B_{sr}	B_{so}	B_g	P_{sr}	P_{so}	P_g	A	B	C	D	E
3	−10.00	A	480	1	1	1							1				
4	−10.00	B	400				1	1	1					1			
5	−10.00	C	230							1	1	1			1		
6	0	D	106	1												1	
7	0	E	315				1			1							1
8	T		−11,100	−10	−10	−10	−10	−10	−10	−10	−10	−10	−10	−10	−10	0	0
9	$P-T$			11.32	9.92	10.00	10.72	9.94	10.00	10.89	9.59	10.00	0	0	0	0	0

TABLE 10

Revised Program

P			1.32	−.08	0	.72	−.06	0	.89	−.41	0	−10.00	−10.00	−10.00	0	0
	V	Q	H_{sr}	H_{ss}	H_g	B_{sr}	B_{ss}	B_g	P_{sr}	P_{ss}	P_g	A	B	C	D	E
−10.00	A	374		1	1							1			−1	
−10.00	B	400				1	1	1					1			
−10.00	C	230							1	1	1			1		
1.32	H_{sr}	106	1												1	
0	E	315				1			1							1
T	−9900.08		1.32	−10.00	−10.00	−10.00	−10.00	−10.00	−10.00	−10.00	−10.00	−10.00	−10.00	−10.00	11.32	0
$P-T$			0	9.92	10.00	10.72	9.94	10.00	10.89	9.59	10.00	0	0	0	−11.32	0

Profit increase over previous solution
−9,900.08+11,100=$1199.92

an equal sign. For example, $H_{sr} = (1)A + (1)D$ or $H_{sr} = A + D$, $H_{ss} = A$, $H_g = A$, $B_{sr} = B + E$, etc.

2. For the column with the highest positive value, in this case Row 6, "D", solve for the variable corresponding to the row being replaced.

$$H_{sr} = A + D;\ D = H_{sr} - A.$$

3. For each column, including Q, substitute this expression each time a coefficient apears in the row being replaced. If a column does not contain a D, the coefficients remain the same for the new matrix.

$$Q = 480\ A + 400\ B + 230\ C + 106(H_{sr} - A) + 315\ E$$
(old matrix)
$$Q = 374\ A + 400\ B + 230\ C + 106\ H_{sr} + 315\ E$$
(new matrix)

$H_{sr} = A + D$ (old matrix)
$H_{sr} = A + (H_{sr} - A)$
$H_{sr} = H_{sr}$ (new matrix)
$D = D$ (old matrix)
$D = H_{sr} - A$ (new matrix)

The other columns do not contain a D, so the coefficients remain the same.

4. Place the coefficients of these new expressions in the matrix, replacing the new variable (H_{sr}) in the space of the old (D) in column V. This has been done in Table 10, "Revised Program".

5. Compute the values for row T and also for row P-T. The difference in the T value for column Q and the previous T value for column Q represents the "profit increase" represented by this new solution. This is shown below each table.

6. Inspect the P-T row and if there are no positive values the optimum program has been determined. If there are positive values continue to repeat the procedure as outlined until no positive values are shown. In order to conserve space several intermediate solutions have been left out of this illustration but the optimum solution is shown in Table 11. This program is represented by the variables appearing in column V and are to be utilized at the level shown by the Q column. For example, in the optimum solution in Table 11, "Optimum Program," the solution is as follows:

$H_g = 374$ = amount of hams to be sold green
$B_g = 315$ = amount of bellies to be sold green
$P_{sr} = 230$ = amount of picnics to be smoked
$H_{sr} = 106$ = amount of hams to be smoked
$B_{sr} = 85$ = amount of bellies to be smoked

When solving linear programming problems by this method, and an optimum is reached, it does not indicate that this is the only optimum solution, but rather that no other solution will result in greater profit. In some instances, there may be two or more possible programs that result in the same profit. This method determines one of them. But the important point

TABLE 11

Optimum Program

P			1.32	−.08	0	.72	−.08	0	.89	−.41	0	−10.00	−10.00	−10.00	0	0
	V	Q	H_{sr}	H_{ss}	H_g	B_{sr}	B_{ss}	B_g	P_{sr}	P_{ss}	P_g	A	B	C	D	E
0	H_g	374		1	1							1			−1	
0	B_g	315					1	1		1	1		1	1		−1
.89	P_{sr}	230							1					1		
1.32	H_{sr}	106	1							1	1				1	
.72	B_{sr}	85				1				−1	−1			−1		1
T	405.82		1.32	0	0	.72	0	0	.89	.60	.60	0	0	− .17	1.32	.72
$P-T$			0	−.08	0	0	−.06	0	0	−1.01	−.60	−10.00	−10.00	−9.83	−1.32	−.72

Profit increase over previous solution
−405.82−2744.18=$3,150.00

here is that a more profitable solution than any previous one has been determined. In this case it amounts to three thousand dollars more than any other solution.

This is the optimum program for the price differences stated before. It would be desirable to know how this program will vary with change in prices.

From the list of costs in Table 6 it can be seen that it will always be more profitable to produce smoked hams rather than to sell them green so long as the price difference exceeds the differences in the cost of production, 5.18 −.50 dollars per hundred pounds. If the difference between selling prices drops below this figure, it will be more profitable to sell hams green. Also notice that in order to have it more profitable to produce smoked hams during overtime, it is necessary to have a price difference of 6.58 −.50, or 6.08 dollars per hundred pounds. It is also possible to determine the optimum levels for other products at different price levels.

ADDITION OF OTHER RESTRICTIONS

These optimum programs can be used as a guide for everyday decisions so long as there are no additional restrictions. Once the problem solving procedure is understood thoroughly, it is easy to continue to a more complex problem which probably represents more accurately the everyday situation.

SELECTING THE OPTIMUM PROGRAM

An optimum program should be available for quick reference for any situation. It is not feasible, of course, to include programs for all possible situations that may arise because of day-to-day differences in restrictions caused by machine breakdowns, sales requirements, etc. However, it would be desirable to have a basis for comparing alternative programs with the optimum program under the constant restriction caused by plant capacity, weight percentages, process capacity, etc. The following summary is a convenient form for presentation of the optimum programs.

A set of tables was developed for all programs for the three average hog weights listed in the text. These were table A, 200 lbs, table B, 240 lbs., and table C, 280 lbs. These three sets of tables are all constructed in the same way so that it will be necessary to describe only one here. The first table in the set gives the system processing plans for hams, the second in the set provides a means for determining an index letter which is used in the third table to determine the optimum processing plan for bellies and picnics.

To determine the optimum program from tables such as these the following procedure is suggested. The data given here are estimated.

Step 1. Determine the difference between the selling prices of the smoked and green products for each product either in dollars per hundred pounds or cents per pound.

	Smoked Product ¢ per lb.	Green Product ¢ per lb.	Difference ¢ per lb.
Hams	43	36.5	6.5
Bellies	38	32.0	6.0
Picnics	41	35.5	5.5

Step 2. For the expected hog input and the average hog weight (or most common weight class) for the day, enter the appropriate tables. All values in the tables are in hundreds of pounds.

Example

Average hog weight .....240 lbs. *See Table 12*
Hog input 2,000
Selling price differential for hams 6.5
Selling price differential for bellies ...6.0
Selling price differential for picnics ..5.5

Step 3. Determine the optimum program for hams. With the above information enter the Table 12 for 240 lb. hogs. The optimum program for hams is

$$H_{ss} - 113 \times 100 = 11{,}300 \text{ pounds}$$
$$H_{ss} = 45{,}100 \text{ pounds}$$
$$H_g = 0 \text{ pounds}$$

TABLE 12

240 lb. Hogs—Hog Input per Day

Selling Differential for Hams	1800			2000			2200		
	H_{ss}	H_{ss}	H_g	H_{ss}	H_{ss}	H_g	H_{ss}	H_{ss}	H_g
8.0	113	395	0	113	451	0	113	507	0
7.5	113	395	0	113	451	0	113	507	0
7.0	113	395	0	113	451	0	113	507	0
6.5	113	395	0	*113*	*451*	*0*	113	507	0
6.0	113	0	395	113	0	451	113	0	507
5.5	113	0	395	113	0	451	113	0	507
5.0	113	0	395	113	0	451	113	0	507
4.5	0	0	508	0	0	451	113	0	507
4.5	0	0	508	0	0	564	0	0	620
4.0	0	0	508	0	0	564	0	0	620

Optimum Program for Hams.

Step 4. Determine the optimum program for bellies and picnics. This optimum program is determined by first finding the index letter from the index chart for the average hog weight (Table 13). Enter the chart by

TABLE 13

Program Index Chart

Selling Price Differential for Picnics											
0	B	B	C	C	D	D	D	D	D	D
7.5	B	B	C	C	D	D	D	D	D	D
7.0	B	B	C	C	D	D	D	D	D	D
6.5	B	B	C	C	D	D	D	D	D	D
6.0	B	B	C	C	D	D	D	D	D	D
5.5	B	B	C	E	F	*F*	F	F	F	F
5.0	A	A	E	E	F	F	F	F	F	F
4.5	A	A	E	E	F	F	F	F	F	F
4.0	A	A	E	E	F	F	F	F	F	F
3.5	A	A	E	E	F	F	F	F	F	F
	3.5	4.0	4.5	5.0	5.5	*6.0*	6.5	7.0	7.5	8.0

Selling Price Differential for Bellies.

TABLE 14

Index	B_{ss}	B_{so}	B_g	P_{ss}	P_{so}	P_g
			1800 hogs per day input			
A	0	0	454	0	0	228
B	0	0	454	228	0	0
C	169	0	285	228	0	0
D	169	285	0	228	0	0
E	397	0	57	0	0	228
F	397	57	0	0	0	228
			2000 hogs per day input			
A	0	0	504	0	0	264
B	0	0	504	264	0	0
C	133	0	371	264	0	0
D	133	371	0	264	0	0
E	397	0	107	0	0	264
F	*397*	*107*	*0*	*0*	*0*	*264*
			2200 hogs per day input			
A	0	0	554	0	0	290
B	0	0	554	290	0	0
C	107	0	447	290	0	0
D	107	447	0	290	0	0
E	397	0	157	0	0	290
F	397	157	0	0	0	290

Optimum Program for Bellies and Picnics.
(Average Hog Weight 240 Pounds).

selecting the row corresponding to the selling price differential for bellies (6.0 cents). The index letter at the intersection in this example is F. Turn to the optimum program table for bellies and picnics corresponding to the average hog weight (Table 14) and find the program corresponding to the index letter and hog input. In this example, the optimum program for bellies and picnics is

B_{ss} ..... 39,700 pounds
B_{so} ..... 10,700 pounds
B_g 0
P_{ss} 0
P_{so} 0
P_g ..... 26,400 pounds

These weights are the amounts of raw hams, bellies and picnics to be processed by the various processes. The above program can be interpreted as follows:

All of the hams are to be smoked.
All of the bellies are to be smoked.
All of the picnics are to be sold green.

By the foregoing set of sample tables the processor can make an intelligent decision based on facts rather than making a haphazard semi-intuitive decision which has been required heretofore.

CONCLUSION

The linear programming technique described here is a useful and powerful tool for decision making. The decision here is whether a packer should sell his ham production fresh or add the additional cost of smoking. The question is which will yield the greatest profit?

In using a linear programming model certain assumptions and limitations are considered which include linearity, divisibility, additivity and finitenesses. Also, added are certain processing assumptions which are that hogs slaughtered in one day can be processed in one day and all of the output can be sold without affecting the market price.

The factors which were entered into the linear programming model and which influence the packer's decision are: input of hogs, weight of hogs, proportion of input weight expected to be available for processing as hams, bellies or picnics. Also included of course are the selling price, production cost and the quantity that can go through the most restrictive process.

The foregoing information is put into a "simple tableau" which is the most generalized form of the Linear Programming model. By repeated solutions it is possible to develop a simple set of tables which can be easily manipulated by the most inexperienced individual. So it is then that the manufacturer can take full advantage of this powerful analytical tool without further concern to the way the information was developed.

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A Physiological Appraisal of Selected Principles of Motion Economy*

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HISTORICALLY, the area of motion study has been subjected to criticism by many people. Physiologists, psychologists, engineers, industrialists, and union officials are represented in the long list of critics. One of the most common criticisms is that even though motion study purports to improve efficiency and reduce fatigue in manual work, there is little physiological evidence to support these claims. On the other hand, motion and time study practitioners can argue that there is also a lack of physiological evidence refuting the application of the principles of motion economy.

A review of much of the research performed in the field of motion study will reveal that it was based on a production or time criterion. Thus, for many years the question, "Will the principles of motion study meet the test of a physiological criterion?", has gone unanswered. This article describes the results of an investigation concerned with partially answering this question.

At the outset of this study, it was necessary to determine a suitable criterion. The use of a number of physiological measures was given consideration. Some of these, such as measuring the lactic acid concentration in the blood, were immediately ruled out as being impractical. On the other hand, heart or pulse rate appeared to be worthy of consideration. Heart rate was particularly attractive because of the portable electro-cardio devices that have been developed recently. However, it was recognized that heart rate may be influenced by many extraneous variables and that any experiment would have to be designed carefully to eliminate contamination of the results.

After several pilot studies had been made to choose a physiological criterion that was statistically satisfactory for this investigation, the criterion which was ultimately selected was the smallest increase in the number of heart beats per minute above resting rate. The at-rest heart rate was observed while the workers assumed the same postural position at which they would perform the assigned task, i.e., sitting if the work was done while sitting or standing if the work was done while standing.

Two types of heart rate measuring devices were used. One of these was a conventional portable electro-cardio machine. The other was a recording-radio-tachometer which was recently built for the Athletic Department at Purdue University (4). This latter device uses electrode microphones to pick up the electrical nerve impulse which initiates the heart beat. The heart beat is then transmitted and recorded on a continuous paper tape.

Several motion study experiments were performed with "increase in heart rate" as the measured variable. The object of the experiments was to appraise several of the motion economy principles by the use of the chosen physiological criterion. The experimental design and procedure were basically the same for each of the experiments.

Each experiment involved the use of several alternate motion patterns to accomplish a specific task. The motion patterns used were indicative of the principle being studied. Therefore, one of the main factors of each experimental design was the method of performing the task.

It was desirable to introduce a quantitative factor as a control element in order to be assured that the measured variable was a valid indicator of task difficulty. This was accomplished by using different levels of work load. If the task involved a turning motion, different levels of torque were used. If a pressure or a lifting motion was involved, several different weights were used. Thus, for a particular task the correlation between increase in heart rate and increase in work load would indicate how well the measured variable indicated task difficulty.

A second motive for using work load as a main factor was to ascertain whether the choice of the best method, as determined by the smallest increase in heart rate, was different for different levels of torque or work load.

Groups of five male university students were chosen at random for participation in each of the experiments. Due to individual differences the operators were considered as one of the main factors in the design of the experiments. However, an attempt was made to control or to eliminate a number of the variables which are known to influence heart rate. Since temperature and relative humidity have

* Based in part on research performed for a Ph.D. dissertation at Purdue University.

a bearing on heart rate, atmospheric conditions were controlled by heating or air conditioning. The kind and amount of clothing worn also affect heart rate. In these experiments the operators worked without clothing above the waist in order to accommodate the cardio-electrodes. Also, the operators were requested to abstain from eating for about two hours prior to participating in the experiment. Sex and age also are factors which have a bearing on heart rate. All of the participants in this research were male college students between the ages of 17 and 25 years.

Other controllable variables which influence the heart rate are working height and rate of work. Where applicable the apparatus was designed so that the working height could be easily adjusted according to the elbow height of each individual operator; thus, this element was treated as constant. A metronome was used so that each operator could monitor his work pace. The number of work-unit cycles accomplished in each three-minute work period were either mechanically or electrically counted in order to assure that each operator worked at the same pace.

Human heart rate is known to vary from day to day and even during the course of the day. The choice of a time of day and the day of the week for each operator's appointment was considered to be randomized, largely by chance of the availability of the students according to class schedules and extra-curricular activities. The operators repeated the experiment on a different day. The purpose of replicating the experiment was to make it possible to segregate that portion of the variance due to non-controlled elements. Also, in each experimental run the sequence of performing the tasks was selected by using a set of random numbers tables. This was done to minimize the influence of the cumulative effects of continued work on the heart rate data.

Each operator performed each combination of work load and method of operation on the occasion of each of his two appointments. The experimental design may be defined in statistical terms as a three factor, twice replicated, completely randomized, mixed model factorial design. The population mathematical expression for these experiments is as follows:

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + \alpha\beta_{ij} + \gamma_k + \alpha\gamma_{ik} + \beta\gamma_{jk} + \alpha\beta\gamma_{ijk} + \varepsilon_{(ijk)l}$$

Y denotes the response.
μ denotes the true response of the over-all mean.
α denotes the effect due to the methods of operation.
β denotes the effect due to operators.
γ denotes the effect due to work load.
ε denotes the effect due to random error.
i denotes the number of levels of methods.
j denotes the number of levels of operators.
k denotes the number of levels of work load.
l denotes the number of replications.

A STUDY OF SOME BASIC METHODS FOR MANIPULATING HANDWHEELS, CROSSBARS, AND HAND LEVERS

The motion economy principle investigated in this portion of the research involves the use of handwheels, crossbars, and hand levers. Barnes states this principle as follows: (1, p. 305)

> Levers, crossbars, and handwheels should be located in such positions that the operator can manipulate them with the least change in body position and with the greatest mechanical advantage.

A separate experiment was used to study each of these three kinds of implements individually. A mechanical brake was mounted on a shaft which had been machined in a manner to permit the use of these devices interchangeably. A mechanical counter was attached to the shaft to count the number of revolutions accomplished during the work period. The whole was mounted on a base so that the shaft could be easily and quickly changed between horizontal and vertical positions. The work height was maintained at 1 to 3 inches below each individual operator's elbow height. Three levels of axial torque were used in each experiment, namely, 25 inch-pounds, 50 inch-pounds, and 75 inch-pounds.

HANDWHEELS

The handwheel used in this experiment was a 10-inch diameter cast iron four-spoke valve wheel. Five different methods of operation (body positions) were used for manipulating the handwheel. In method 1 the operator stood erect facing the vertical plane of the wheel. He pulled upward with his right hand and pushed downward with his left hand, thus causing a counter-clockwise rotation of the wheel. Method 2 differed from method 1 only in that the right hand pushed downward and the left hand pulled upward with a resultant clockwise rotation. In method 3 the wheel was mounted in the horizontal plane; the operator stood erect and used both hands to rotate the wheel in a clockwise manner, i.e., the right hand pulled and the left hand pushed. In method 4 the wheel was mounted in the vertical plane. The operator stood at the left edge of the wheel with the plane of his body perpendicular to the plane of the wheel. He worked standing in a bent position in order to place his right hand on the lower edge of the wheel and his left hand on the top edge. He pushed with his right hand and pulled with his left hand, thus causing a counter-clockwise rotation. Method 5 differed from method 4 only in that the operator stood in a slightly bent position at the right edge of the wheel, with his right hand pushing the top of the wheel and his left hand pulling from the bottom of the wheel. This action again caused counter-clockwise rotation of the wheel. These manipulative methods are similar to the ones described by Barnes (1, pp. 308-309).

Beginning with the method which resulted in the smallest average increase in the number of heart beats per minute, the rank order of the methods was found to be 2, 1, 4, 3, and 5. The analysis of variance showed that the factor "methods" was statistically significant at the 10% level but not at the 5% level. A Newman-Keuls multiple contrasts test revealed that the only two methods which

were significantly different from each other were methods 2 and 5. These were the methods with the smallest and the largest increase in heart rate. *According to these findings the choice of a method for operating this handwheel under these conditions does not result in a significant difference in the physiological cost of operation, as indicated by heart reaction, unless the choice is between methods 2 and 5.*

The variance due to the main effect of operators was found to be highly significant, but this was to be expected because of individual operator differences. Also, the variance due to the main effect of torque was highly significant. This confirmed that the measured variable was indeed indicative of task difficulty. The interaction between methods and torque was found to be non-significant, i.e., the choice of a method for operating this handwheel does not depend upon the amount of axial torque within the range used in this experiment.

CROSSBARS

A 10-inch crossbar was used in this experiment. Again five different operating methods or body positions were used. These are similar to the manipulative methods used in the crossbar experiment reported by Barnes (1, pp. 308-309). In method 1 the operator stood erect facing the vertical plane of the cross. He grasped the horizontal bar with his right hand and pulled upward while his left hand grasped the opposite end of the bar and pushed downward; thus the rotation of the crossbar was counter-clockwise. Method 2 was similar to method 1 except that the right hand pushed downward and the left hand pulled upward, thus imparting a clockwise motion to the crossbar. In method 3 the crossbar was mounted in the horizontal plane; the operator stood erect and used both hands to turn the crossbar in a clockwise manner, i.e., his right hand pulled one spoke of the cross and his left hand pushed on the opposite spoke. In method 4 the crossbar was mounted in the vertical plane. The operator stood at the left edge of the crossbar with the plane of his body perpendicular to the plane of the cross. He worked in a bent position in order to push with his right hand on the vertical spoke beneath the axis and to pull with his left hand on the opposite spoke above the axis. The resultant rotation of the crossbar was counter-clockwise. Method 5 differed from method 4 in that the operator stood in a slightly bent position at the right edge of the cross so that his right hand could push the upper vertical spoke while his left hand pulled on the opposite spoke, thus again causing counter-clockwise rotation. These operating positions resemble those used in the handwheel experiment.

The findings of this experiment revealed that method 2 resulted in the smallest increase in heart rate. The rank order of the methods was 2, 1, 3, 5, and 4, with only a very small difference between methods 4 and 5. The analysis of variance indicated that the variance due to the main effect of methods was significant at the 1% level. A Newman-Keuls multiple contrasts test showed that method 2 was significantly different from each of the other methods, but none of the other methods were significantly different from each other. *According to these findings it appears that, under the conditions of this experiment, method 2 results in the least human cost in terms of heart rate increase.*

Again the variance due to operators was found to be highly significant as was the variance due to torque. The interaction between methods of operation and torque was found non-significant.

HAND LEVERS

A reversible ratchet socket wrench was used as the lever in this experiment. A ratchet wrench was selected so that the lever could be returned to the starting position without working against the axial torque on the return stroke. The effective length of the lever arm was 9 inches. Six different operating methods were studied in this investigation. These manipulative methods are similar to the ones described by Barnes (1, p. 307).

In method 1 the operator stood erect beside the lever. The axis of the socket was horizontal as was the starting position of the lever. The operator pushed the lever downward against the axial torque load, thus causing the axis to rotate in a clockwise direction. Method 2 differed from method 1 only in that the ratchet was reversed and the operator pulled the lever upward, thus imparting a counter-clockwise motion to the shaft. In method 3 the axis of the brake and, of course, of the socket also, was in the horizontal position but the lever was in the vertical position. The operator stood erect and to the observer's right of the brake shaft and pushed the lever away from him. Method 4 was similar to method 3, except that the ratchet was reversed so as to permit the operator to pull the lever towards himself, thus causing clockwise rotation of the axis. In method 5 the axis of the brake was mounted vertically so that the lever arm would turn in the horizontal plane. The operator pushed the lever against the axial torque load, thus causing counter-clockwise rotation of the shaft. The same arrangement was used in method 6 except that the ratchet was reversed so that the operator could pull against the load with a resultant clockwise rotation of the brake shaft.

Beginning with the smallest average increase in heart rate, the rank order of the six methods was 1, 5, 2, 6, 4, and 3. However, there was not a great deal of difference among the six response means. The analysis of variance indicated that the variance due to the six manipulative methods was not significant, even at the 10% level; therefore, a contrasts test on the difference between paired means was obviated.

Again the main factor of operators was found significant. Also the main factor of torque was found significant. This was empirical proof that the measured variable

was indicative of task difficulty. The interaction between methods of operation and torque was non-significant.

According to these findings, *there was no evidence that the physiological cost, in terms of increase in heart beats, was significantly different for the methods used to manipulate the hand lever.* Also the same was generally true for most of the crossbar and handwheel operating positions. In other words, the use of the different manipulative methods for these devices did not result in a sufficient difference in increase in heart rate to justify the recommendation of one method over some other method except in isolated cases. In the case of handwheels, method 2 appeared to be better than method 5. In the case of crossbars, method 2 appeared to be better than the other four methods.

The motion economy principle in question was established on the basis of empirical investigations performed by Kuhne (3), and it is explained and illustrated by Barnes (1, pp. 305-312). The maximum operant load was the criterion of choice used to select the best motion position. This canon maintained that the best motion economy method of operation was the one in which the operator assumed the position at which he could exert his greatest strength, i.e., enjoy the greatest mechanical advantage. This variable was measured by the maximum force against which the operator could cause the device to move.

It is unfortunate that the available information on the design of the original experiments is insufficient for the application of modern statistical methods in order to effect mathematical comparisons. However, inspection of the graphical presentation of the results obtained at the comparable work height of 42½ inches indicates that the original findings are in general agreement with those obtained by the statistical evaluation of the heart rate study data. In other words, *the physiological evidence as indicated by increased heart rate does not refute the motion economy principle which was formulated with the mechanical advantage criterion.*

A STUDY OF FOOT PEDAL MOTIONS

The purpose of this experiment was to investigate foot pedal motions with the criterion of increased heart rate. There are many variations in the size and shape of foot pedals, but basically there are five fundamental designs. A model of each of these five designs was built for use in this research. The movable section of each pedal measured 4 by 10 inches. A mechanical counter was attached to each pedal to count the work unit cycles so as to have a measure of how well the operators maintained pace with the metronome. The surface of each pedal was covered with a high friction material.

Pedal 1 had the fulcrum at the end under the heel. A small strip across the end served as a stop for positioning the shoe. Both the heel and the ball of the foot were in contact with the plane of the pedal. Pedal 2 had the fulcrum at the toe end which was 4 inches above the base plane. Both the heel and the ball of the foot were in contact with the plane of the pedal. Pedal 3 had a stationary rest for the heel. A small strip across the front of this part was used as an aid to hold the foot in position. The fulcrum for the movable part of the pedal was mounted at the front of the stationary heel rest, i.e., just in front of the heel under the arch. Pedal 4 had the fulcrum at the toe end. The ball of the foot rested on the pedal and the heel hung over the end of the pedal. When the pedal was fully depressed the heel came in contact with a stationary section. Pedal 5 had the fulcrum under the arch. A small strip across the pedal at the front edge of the heel served as a positioning device.

These pedals are similar to the ones used by Barnes, Hardaway, and Pololsky in an experiment to determine the best foot pedal when the criterion was the maximum speed of operation (2). Their operators worked while sitting.

Three levels of work load were used in the pedal experiment: 5 pounds, 10 pounds, and 15 pounds. These weights were suspended from a cord by detachable snaps. The cord was threaded through a system of pulleys which was necessary to change the direction of the force. A separate pulley system was used for each pedal. The cord was attached to a metal arm extending from the front of the pedal. The same size and length of extension was used for each pedal. A metal container was hung from each of the cords. These containers held just enough sand to counter-balance the friction in the individual system and to hold the foot pedal in its normal position when it was not in use. The operators manipulated the pedals while standing.

Beginning with the pedal which resulted in the smallest average increase in heart rate, the rank order of the pedals was found to be 1, 2, 4, 5, and 3. Barnes and his associates (2) ranked the pedals, beginning with the pedal which could be operated fastest, as follows: 1, 2, 3, 5, and 4. Although their operators manipulated the pedals while sitting and used only one work load, *their choice of the best two foot pedals is the same as the choice indicated when the smallest increase in heart rate was the criterion.*

The analysis of variance showed that the variance due to the main effect of pedals was significant at the 10% level. A Newman-Keuls multiple contrasts test showed that pedals 1 and 2 were not significantly different from each other, but both of these were significantly different from the other three pedals. Pedal 3 was not significantly different from pedals 4 and 5, and the latter pair of pedals were not significantly different from each other.

The variance due to work load was found highly significant; this was proof again that the experimental measured variable was indicative of task difficulty. The two-factor interaction of pedals and work load was found non-significant, thus indicating that the choice of a pedal is

not dependent upon the force the pedal must move. The operator effect was highly significant, but this variance was attributed to the individual differences among the operators.

A STUDY OF SIMULTANEOUS AND SYMMETRICAL HAND MOTIONS

The purpose of this experiment was to investigate the motion study principles relating to the simultaneous and symmetrical use of the hands with minimum increase in heart rate as the criterion. Four methods of operation, i.e., motion patterns, were used in this experiment. In order to comply with the experimental design requirement of a control to indicate that the measured variable of increased heart rate was indicative of task difficulty, three different pairs of weights were used. These weights were made of metal and each had the same size handle and body diameter. The equally spaced levels of these weights were 0.5 pounds, 2.5 pounds, and 4.5 pounds. The choice was made of a two-pound increment between levels of weights in accordance with the results of a pilot study. The purpose of the pilot study was to determine statistically the range in which the measured variable was discriminatory.

Because the experiment required a high degree of control of the symmetry of the motion patterns, it was necessary to provide some means to fix the stations between which the objects (weights) would be moved. At most, an experimental method would require four stations. Furthermore, the experiment called for a means to indicate that, where required, the motions were being performed simultaneously and not slightly out of phase with each other. In addition, it was desirable to have some way to determine the number of work unit cycles performed in a specified time period in order to ascertain how well each operator maintained pace with the metronome signal. These latter two experimental requirements were fulfilled by electrical means. Each of the station fixtures had a normally open microswitch built into its base. When a weight was properly positioned on the fixture it actuated the microswitch, thus initiating an electrical signal. Each fixture had two holes, one each in two diagonally opposite corners. The table top was equipped with metal pegs, and the fixtures were aligned by placing the holes over the fixed pegs. This permitted exact duplication of the work positions each time a change in work method required a different arrangement of the stations.

The layouts of the stations for each of the four methods of operation, i.e., motion patterns are shown in Figure 1. The operators performed all of these tasks while seated. All of the operators performed all of the tasks at the same pace. Method 1 required that the operator use his right hand to move the weight alternately between stations 1 and 2 while his left hand remained idle. The geometric relationship between stations 1 and 2 was held constant for methods 1, 2, and 3. The purpose of using

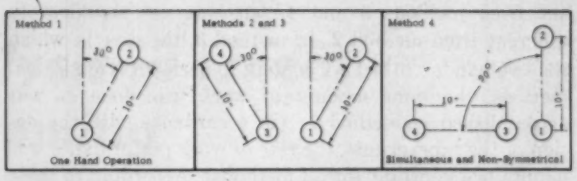

FIG. 1. The Four Hand Motion Methods. (Method 2 and Method 3 are identical with the exception that Method 2 is Simultaneous and Symmetrical while Method 3 is Non-Simultaneous and Symmetrical. The two methods are combined in the drawing.)

method 1 was to employ the results in a comparison with two-handed operations in order to appraise the motion study canon regarding the use of both hands in a task.

In method 2 the stations were arranged to permit opposite and symmetrical hand motions. The right hand grasped the weight on station 1 while the left hand grasped the weight on station 3. At the same time that the right hand moved its weight to station 2 and released it, the left hand moved its weight to station 4 and released it, thus completing the first half of the work unit cycle. In the second half of the work unit cycle the right hand grasped the weight on station 2 at the same time that the left hand grasped the weight on station 4. Simultaneously the hands returned their loads to their original stations. The operator continued this work cycle throughout the work period. The purpose of this method was to obtain the heart rate data for simultaneous and symmetrical motions.

The same arrangement of the station fixtures used in method 2 was again employed in method 3. While the operator's left hand remained idle, he moved the load on station 1 to station 2 and then from station 2 back to station 1. Immediately following this maneuver the operator used his left hand to move the weight on station 3 to station 4 and from there back to station 3 while the right hand remained idle. The operator repeated this sequence throughout the work period. The purpose of this method was to provide a symmetrical but non-simultaneous set of hand motions.

In method 4 the fixtures were arranged so that the center line of stations 1 and 2 would be perpendicular to the extended center line of stations 3 and 4. The sequence of the hand motions in this method was the same as that for method 2, i.e., the two hands worked simultaneously. However, the pattern of the motions was not symmetrical. Thus, this method involved simultaneous but non-symmetrical hand motions. Again the operator repeated this work cycle throughout the experiment.

The analysis of variance indicated that the variance due to different methods of operation was highly significant. There, the Newman-Keuls technique was employed to evaluate statistically the significance of the differences between pairs of methods. Method 1, the single-handed operation, resulted in a smaller increase in heart rate than the other methods. This method was significantly differ-

ent from methods 3 and 4, but was not significantly different from method 2. In method 3, the case in which the two hands worked alternately to perform symmetrical motions, the same amount of work was done as was accomplished in method 1; (in accordance with the design of the experiments, the rate of work performance was maintained constant for all methods). According to these findings it appears that it is better to use one hand to accomplish a specified task than to employ both hands alternately to accomplish the task. In other words, *for an equal amount of work performed, the one-handed operation resulted in a significantly smaller increase in heart rate than did the two-handed non-simultaneous motions.*

Methods 2 and 4 also involved the same amount of work but method 2 resulted in a smaller increase in heart rate than did method 4, and the difference between the mean increases was found statistically significant. According to these findings *it appears that the simultaneous and symmetrical motions method was better than the simultaneous and non-symmetrical motions method.*

Method 1 was found significantly different from method 4, but the latter method accomplished twice as much work. If the amount of work output is disregarded, it appears that simultaneous non-symmetrical motions caused a significantly greater increase in heart rate than the method in which one hand was idle while the other hand performed the task.

Method 1 resulted in a smaller increase in heart rate than did method 2. However, even though the use of method 2 accomplished twice as much work as method 1, the contrast test did not show that these two methods were statistically significantly different from each other. According to these findings *it appears that, at the rate of work performance used in this experiment, there was some evidence that the use of both hands simultaneously in symmetrical motion patterns is probably justified.*

The above conclusion was further supported by the fact that methods 2 and 3 were also found to be not significantly different from each other. Furthermore, in spite of the fact that method 2 resulted in the smaller increase in heart rate, its use resulted in accomplishing twice as much work as the use of the one-hand-at-a-time motions of method 3. *Evidently, for these working conditions, simultaneous and symmetrical hand motions, in addition to acomplishing twice as much work, are physiologically better than non-simultaneous and symmetrical hand motions.*

Method 3 was found to be not significantly different from method 4. The former method resulted in a lower physiological cost in terms of increased heart rate, but it resulted in accomplishing only half the amount of work done when the latter method was used. According to these findings it appears that the use of simultaneous and non-symmetrical hand motions is probably justified when the alternative motion pattern is non-simultaneous and symmetrical.

The variance due to the main effect of operators was found highly significant. This, of course, was attributed to individual differences among the operators.

The variance due to different levels of work load was also found highly significant. The interaction between methods of operation (motion patterns) and work load (weight handled) was found to be significant. A graph of increased heart rate versus work load for each motion pattern revealed that none of the curves intersected, but they were not parallel. This may indicate that for some levels of work load outside the range used, the heart rate response data may point to the use of some different motion pattern than was selected from this study.

The levels of the work load in each of the experiments were evenly spaced. This was done to simplify the calculations for the curves showing the relationship between increased heart rate and increased work load. This information in itself was not pertinent to the object of the research, but as a matter of interest, it was aranged that the data be taken in a matter which permitted easy calculations of the relationships. For what it may be worth, the relationship between these two variables was found to be highly linear statistically, and the quadratic component was non-significant in all cases. A word of caution is appropriate, namely, that a canon is neither expressed nor implied because this relationship may or may not apply to other tasks, operators, levels of work load, long periods of continuous work, or working conditions.

In summary, it may be concluded that the use of increased heart rate as a physiological criterion did not provide evidence for the refutation of these particular motion economy principles.

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Sensitivity Analysis in Linear Programming

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THE general linear programming problem is to find non-negative values of n variables which maximize a given linear function of the variables, subject to m given linear constraints. The solution to this problem has been formulated by Dantzig (4) into a systematic iterative procedure, now known as the *simplex method* (2) (3) (6). It may be recalled that the first step in this method is to express the restrictions in the form:

$$\sum_{j \notin B} a_{ij}x_j + x_i = b_i, \qquad i \in B, \qquad \text{Eq. 1.}$$

where the set B is defined by:

$$B = \{i \mid x_i \text{ is a basis variable in the initial tableau (formed using Eq. 1.)}\}.$$

The criterion function (primary objective function) can be written as:

$$C(x) = \sum_{j=1}^{m+n} c_j x_j \qquad \text{Eq. 2.}$$

In the formulation of the foregoing problem it is presumed that the constants of the problem are known with absolute precision and do not change with time. However, in many cases, only estimates of these values are available, and the values may have to be changed when better estimates are available. The values may also change with time, for example, when technological improvements result in an increase in the production rate. Further, in some cases, the optimum solution obtained using a set of constants may have to be changed to satisfy secondary objectives, such as customer good-will etc. The importance of this aspect of management problems is borne out by the remarks of the commentators on the papers on linear programming during the First International Conference on Operations Research (5).

In this article the effect of changing either one constant or one variable of the problem will be studied. Further, the variation is restricted to the case where the new optimal solution does not necessitate a change of basis in the final tableau obtained for the original problem.[2] The specific questions dealt with in this paper are:

1. **What is the optimal solution when one of the constants of the problem (either some c_i or b_i or a_{ij}) is changed without necessitating a change of basis? What is the new value of the criterion function?**
2. **When the value of one of the variables is changed by a given amount, what changes are necessary in the values of the other variables if the reduction in the value of $C(x)$ is to be a minimum?**

Analysis of this nature, which may be called *sensitivity analysis*, is useful in many practical contexts. In certain situations, it is helpful to know the amount of change in a constant which will change the basis. For example, consider a production context where the production is to be scheduled over a certain set of facilities. In this case, knowledge of the amount of change in a constant which will necessitate the use of other facilities will be helpful in planning. When the value of a variable is changed to satisfy secondary objectives, the optimal changes in the values of the other variables to insure a minimum reduction in the value of the criterion function will be of interest. The examples given later will illustrate some of the practical applications of sensitivity analysis.

ILLUSTRATIVE PROBLEM

For the sake of clarity, the method of analysis will be illustrated using the following example. Suppose a manufacturing concern deals in three products, *1* through *3*. The production rates, space requirements for storage, and profits are as given in Table 1. The maximum time available for production may be assumed to be 8 hours per day, and the maximum amount of storage space available as 400 square feet. Further, suppose that the maximum demand for product *2* is expected to be 70 pieces per day. The problem is then to find the number of pieces of each product to be produced per day to maximize profit.

Denoting the number of pieces of each product produced per day by x_1, x_2, and x_3 respectively, the problem

[1] The author is indebted to Dr. Loring G. Mitten of Northwestern University for valuable counsel and criticism during the entire course of the study. Further, acknowledgement is made of the prior work of Dr. A. Charnes in the field of sensitivity analysis in linear programing (1). Appreciation is also due to Mr. W. R. Lynn and Dr. A. Rosenberg for helpful discussions.

[2] The method of handling variations in more than one constant and also the case involving a change of basis are discussed in an article which will be published in the November-December issue of the *Journal of Industrial Engineering*. This provides a method of deriving the new optimal simplex tableau when a set of constants of the problem are changed, and hence is useful in studying certain dynamic systems.

TABLE 1

Product	1	2	3
Production rate (pcs. per hour)	20	60	15
Storage space (sq. ft. per pc.)	4	2	3
Profit ($ per pc.)	20	10	20

can be expressed in the form given in Eq. 1. and Eq. 2. as follows:

Maximize: $C(\mathbf{x}) = 20x_1 + 10x_2 + 20x_3 + 0x_4 + 0x_5 + 0x_6$, subject to the restrictions:

$$\begin{aligned} 3x_1 + x_2 + 4x_3 + x_4 &= 480, \\ 4x_1 + 2x_2 + 3x_3 + x_5 &= 400, \\ x_2 + x_6 &= 70, \end{aligned}$$

where the time restriction is expressed in minutes, and x_4 through x_6 are the slack variables.

From the above set of equations, the initial tableau (Table 2) can be formed. Proceeding by the simplex method, we have the final tableau given as Table 3.

TABLE 2

		c_j	20	10	20	0	0	0
c_i	Basis	b	x_1	x_2	x_3	x_4	x_5	x_6
0	x_4	480	3	1	4	1	0	0
0	x_5	400	4	2	3	0	1	0
0	x_6	70	0	1	0	0	0	1
	z_j	0	0	0	0	0	0	0
$w_j = (c_j - z_j)$			20	10	20	0	0	0

TABLE 3

		c_j	20	10	20	0	0	0
c_i	Basis	b'	x_1	x_2	x_3	x_4	x_5	x_6
20	x_3	112	.4	0	1	.4	−.2	0
10	x_2	32	1.4	1	0	−.6	.8	0
0	x_6	38	−1.4	0	0	.6	−.8	1
	z_j'	2560	22	10	20	2	4	0
$w_j' = (c_j - z_j')$			−2	0	0	−2	−4	0

NOTATION

We now proceed to state some of the notation used in this study. Consider a change in a variable or constant, For example, let a_{ij} be changed to a_{ij}^*. We will denote the change by $\Delta a_{ij} = (a_{ij}^* - a_{ij})$. The maximum and minimum possible values of Δa_{ij}, without changing the basis in the final tableau, will be denoted by $\overline{\Delta} a_{ij}$ and $\underline{\Delta} a_{ij}$ respectively.

Further, for convenience, we will denote $(c_j - z_j)$ by w_j. It may be recalled that both

$$z_j = \sum_{i \in B} c_i a_{ij} \text{ and } w_j$$

have been evaluated and are entered in the bottom rows of column j of the simplex tableau.

In this study it will be necessary to relate the elements of the initial tableau with the elements of the final tableau. Consider the initial tableau. Corresponding to this tableau we have already defined a set $\boldsymbol{B} = \{j \mid x_j \in \text{basis in the initial tableau}\}$. The element at the intersection of the row corresponding to a variable $x_P (P \in \boldsymbol{B})$ and the column corresponding to a variable x_Q will be denoted by a_{PQ}. Likewise, the element b_P will be in x_P's row. To illustrate the notation, in Table 2 we have $\boldsymbol{B} = \{4, 5, 6\}$, $a_{52} = 2$, $b_4 = 480$, $z_4 = 0$ and $w_2 = 10$.

Now consider the final tableau, the elements of which will be denoted with a prime. The basis variables in this tableau can be identified by defining a set $\boldsymbol{B}' = \{j \mid x_j \in \text{basis in the final tableau}\}$. The element at the intersection of x_R's row $(R \in \boldsymbol{B}')$ and x_T's column will be denoted by a_{RT}'. Similarly, the element b_R' will be in x_R's row. For example, in Table 3 we have $\boldsymbol{B}' = \{3, 2, 6\}$, $a_{31}' = .4$, $b_3' = 112$, $z_1' = 22$ and $w_1' = -2$.

In the analysis that follows the optimal changes necessary when a variable or constant is varied will be given in the form of an algorithm. It will then be illustrated with an example. Mathematical justification for the same will be given after the statement of all the algorithms.

VARIATION IN c_j

In this section we study the variation in $c_j, j = 1, \cdots, m+n$, the coefficients of the variables in the criterion function.

Algorithm 1a. Change in c_J, $J \notin \boldsymbol{B}'$, i.e., x_J is not in the basis in the final tableau.

(i) The maximum change possible in c_J without changing the basis in the final tableau is given by:

$$-\infty \leqq \Delta c_J \leqq -w_J', \qquad J \notin \boldsymbol{B}'.$$

In the notation given earlier, we have $\underline{\Delta} c_J = -\infty$ and $\overline{\Delta} c_J = -w_J'$. w_J' has been evaluated in the last row (column J) of the final tableau obtained by the simplex method.

(ii) For a change in c_J within the limits indicated above, i.e., for $\underline{\Delta} c_J \leqq \Delta c_J \leqq \overline{\Delta} c_J$, the change necessary in the values of the variables is given by:

$$\Delta x_j = 0, \quad j = 1, \cdots, m+n,$$

i.e., the optimality of the solution is unaffected.

(iii) For a change in c_J within the limits indicated above, the change in the value of the criterion function is given by:

$$\Delta C(\mathbf{x}) = 0,$$

i.e., the value of the criterion function is unaffected.

Algorithm 1b. Change in c_J, $J \in \boldsymbol{B}'$, i.e., x_J is a basis variable in the final tableau.

(i) The maximum change possible in c_J without changing the basis in the final tableau is given by:

$$\underline{\Delta}c_J \leqq \Delta c_J \leqq \overline{\Delta}c_J,$$

where

$$\underline{\Delta}c_J = \max\left[\frac{w_k'}{a_{Jk}'}, -\infty\right], \quad a_{Jk}' > 0 \text{ and } k \notin \boldsymbol{B}',$$

and

$$\overline{\Delta}c_J = \min\left[\frac{w_k'}{a_{Jk}'}, \infty\right], \quad a_{Jk}' < 0 \text{ and } k \notin \boldsymbol{B}'.$$

(ii) For a change in c_J within the limits indicated above, the change necessary in the values of the variables is given by:

$$\Delta x_j = 0, \quad j = 1, \cdots, m+n,$$

i.e., the optimality of the solution is not affected.

(iii) For a change in c_J within the limits indicated above, the change in the value of the criterion function is given by:

$$\Delta C(\mathbf{x}) = \Delta c_J x_J.$$

Example

In the illustrative problem given earlier, if the coefficient c_1 of x_1 is increased by more than 2 units, using Algorithm 1a it can be verified that Table 3 cannot be the solution tableau.

To illustrate the application of Algorithm 1b, consider decrease in c_2, the coefficient of x_2. Table 3 will no longer be the solution tableau if c_2 is changed by more than

$$\underline{\Delta}c_2 = \max\left[\frac{-2}{1.4}, \frac{-4}{.8}\right] = -1.44.$$

Similarly, the maximum increase in c_2 without affecting the optimality of the solution is given by

$$\overline{\Delta}c_2 = \frac{-2}{-.6} = 3.33.$$

CHANGE IN b_i

We now proceed to study the effect on the solution if a restraining constant b_i, $i \in \boldsymbol{B}$, is changed. The following steps will give the corresponding optimal changes necessary in the values of the variables, and the change in the criterion function.

Algorithm 2

(i) The solution to the problem with b_I changed by Δb_I will have the same basis variables as the original problem if we have:

$$\underline{\Delta}b_I \leqq \Delta b_I \leqq \overline{\Delta}b_I,$$

where

$$\underline{\Delta}b_I = \max\left[\frac{-x_j}{a_{jI}'}, -\infty\right], \quad a_{jI}' > 0 \text{ and } j \in \boldsymbol{B},$$

and

$$\overline{\Delta}b_I = \min\left[\frac{-x_j}{a_{jI}'}, \infty\right], \quad a_{jI}' < 0 \text{ and } j \in \boldsymbol{B}'.$$

In the foregoing equations, a_{jI}' are the elements in the final tableau in column I, as per the notation adopted before.

(ii) For a change in b_I within the limits indicated above, the corresponding optimal change in the values of the variables is given by:

$$\Delta x_j = \begin{cases} \Delta b_I a_{jI}' & , \ j \in \boldsymbol{B}' \\ 0 & , \ j \notin \boldsymbol{B}'. \end{cases}$$

(iii) The change in the value of the criterion function corresponding to the change in the values of the variables as indicated above, is given by:

$$\Delta C(\mathbf{x}) = \Delta b_I z_I'$$

where

$$z_I' = \sum_{j \in \boldsymbol{B}'} c_j a_{jI}'$$

given in column I of the final tableau.

Illustration

Suppose, in the example given earlier, the cost of providing additional storage space is \$50.00 per square ft. From Algorithm 2, each additional unit of storage space will result in an increase in $C(\mathbf{x})$ by $z_4' = 4$ dollars. This implies a gross return (before interest, depreciation, etc.) of 8 percent on additional investment. The maximum possible increase in storage space with this rate of return is given by:

$$\overline{\Delta}b_4 = \min\left[\frac{-112}{-.2}, \frac{-38}{-.8}\right] = 47.5 \text{ sq ft.}$$

If b_4 is increased, by say 40 sq. ft., the corresponding change in the values of the basis variables, from Step 2 of the algorithm, are $\Delta x_3 = -8$, $\Delta x_2 = 32$ and $\Delta x_8 = -32$. The corresponding increase in $C(\mathbf{x})$ is given by (40)4 = \$160.

Similarly, if the time restriction can be relaxed, say through overtime payment, we have:

$$\overline{\Delta}b_4 = \frac{-32}{-.6} = 53.33,$$

and

$$\frac{\Delta C(\mathbf{x})}{\Delta b_4} = z_4' = 2.0.$$

Hence, it is profitable to increase production time with over-time payment at a maximum rate of $2.00 per minute or $120.00 per hour to the extent of 53.33 minutes per day.

CHANGE IN a_{ij}

We now consider the effect on the solution when one of the coefficients a_{ij} in the restraining equations is changed. If a_{IJ} is changed by Δa_{IJ}, the changes necessary in the values of the variables to make them optimal, and the corresponding change in the value of the criterion function, can be obtained using the following algorithms.

Algorithm 3a. Change in a_{IJ}, $J \in \boldsymbol{B}'$, i.e., x_J is a basis variable in the final tableau.

(i) The maximum possible change in a_{IJ} without necessitating a change of the basis in the final tableau is given by:

$$\overline{\Delta} a_{IJ} = \min \left[\frac{x_i}{(a_{iI}' x_J - a_{JI}' x_i)}, \frac{-w_j'}{(z_I' a_{Jj}' + w_j' a_{JI}')}, \infty \right],$$

where the first term is evaluated for all $i \in \boldsymbol{B}'$ satisfying $a_{iI}' x_J > \max\ [0,\ a_{JI}' x_i]$, and the second term for all $j \notin \boldsymbol{B}'$ satisfying $z_I' a_{Jj}' > \max\ [0,\ -w_j' a_{JI}']$.

$$\underline{\Delta} a_{IJ} = \max \left[\frac{x_i}{(a_{iI}' x_J - a_{JI}' x_i)}, \frac{-w_j'}{(z_I' a_{Jj}' + w_j' a_{JI}')}, -\infty \right],$$

where the first term is evaluated for all $i \in \boldsymbol{B}'$ satisfying $a_{iI}' x_J < \min\ [0,\ a_{JI}' x_i]$, and the second term for all $j \notin \boldsymbol{B}'$ satisfying $z_I' a_{Jj}' < \min\ [0,\ -w_j' a_{JI}']$.

(ii) For a change in a_{IJ} satisfying $\underline{\Delta} a_{IJ} \leqq \Delta a_{IJ} \leqq \overline{\Delta} a_{IJ}$, the optimal change necessary in the values of the variables is given by:

$$\Delta x_i = \begin{cases} -\dfrac{\Delta a_{IJ} a_{iI}' x_J}{1 + \Delta a_{IJ} a_{JI}'}, & i \in \boldsymbol{B}' \\ 0, & i \notin \boldsymbol{B}'. \end{cases}$$

(iii) The change in the value of the criterion function corresponding to the above changes is given by:

$$\Delta C(\mathbf{x}) = -\frac{\Delta a_{IJ} z_I' x_J}{1 + \Delta a_{IJ} a_{JI}'}.$$

Algorithm 3b. Change in a_{IJ}, $J \notin \boldsymbol{B}'$, i.e., x_J is not a basis variable in the final tableau.

(i) The maximum possible change in a_{IJ} without necessitating a change in the basis, is given by:

$$\underline{\Delta} a_{IJ} \leqq \Delta a_{IJ} \leqq \overline{\Delta} a_{IJ},$$

where

$$\underline{\Delta} a_{IJ} = \begin{cases} -\infty & \text{when } z_I' \leqq 0 \\ \dfrac{w_J'}{z_I'} & \text{when } z_I' > 0, \end{cases}$$

and

$$\overline{\Delta} a_{IJ} = \begin{cases} \infty & \text{when } z_I' \geqq 0 \\ \dfrac{w_J'}{z_I'} & \text{when } z_I' < 0. \end{cases}$$

(ii) For a change in a_{IJ} within the above limits, we have

$$\Delta x_i = 0, \qquad i = 1, \cdots, m + n,$$

i.e., the solution is still optimal.

(iii) For a change in a_{IJ} within the limits indicated above, the change in the criterion function is given by:

$$\Delta C(\mathbf{x}) = 0,$$

i.e., the value of the criterion function is unaffected.

Illustration

In the illustrative problem given before, suppose that through technological improvements the production rate of product *2* can be increased to 120 pcs. per hour. We then have $\Delta a_{42} = -.5$. Using step (i) of Algorithm 3a we get $\underline{\Delta} a_{42} = -\infty$, as there are no rows or columns satisfying the conditions for evaluating the first two terms. From step (ii) the optimal change in the variables is given by:

$$\Delta x_3 = -\frac{(-.5)(.4)(32)}{1 + (-.5)(-.6)} = 4.9$$

$$\Delta x_2 = -\frac{(-.5)(-.6)(32)}{1 + (-.5)(-.6)} = -7.4$$

$$\Delta x_6 = -\frac{(-.5)(.6)(32)}{1 + (-.5)(-.6)} = 7.4$$

and the change in the value of the criterion function is given by:

$$\Delta C(\mathbf{x}) = -\frac{(-.5)(2)(32)}{1 + (-.5)(-.6)} = 24.$$

Hence, the maximum increase in $C(\mathbf{x})$—if production of the various items is changed, as evaluated above, to the new optimal values—is $24.00 per day. This information can be a vital factor in deciding on additional expenditure for increasing the production rate of product *2*.

Now consider an increase in the production rate of product *1*. Using Algorithm 3b, we have:

$$\underline{\Delta} a_{41} = \frac{w_1'}{z_4'} = \frac{-2}{2} = -1,$$

i.e., only if the production rate of product *1* is more than 30 pcs. per hour it will be profitable to produce it.

CHANGE IN THE OPTIMAL VALUES OF x_i

In this section we turn to another aspect of the study, namely the effect of changing the optimal values of the variables. So far it was presumed that maximizing

$C(\mathbf{x})$ is the only objective. However, in many cases the results obtained by this approach have to be modified to satisfy other objectives. For example, the values of the variables may have to be increased to meet contractual agreements. We now proceed to show how this can be done with minimum penalty in terms of the primary objective function.

It is evident that any deviation from the optimum solution obtained by the simplex method will reduce $C(\mathbf{x})$. In order that the reduction in $C(\mathbf{x})$ is a minimum, the variables have to be changed according to the following algorithms.

Algorithm 4a. Change in x_K, $K \notin \boldsymbol{B}'$, i.e., x_K is not a basis variable in the final tableau.

(i) The maximum change possible in x_K without changing the basis in the final tableau is given by:

$$0 \leqq \Delta x_K \leqq \bar{\Delta} x_K,$$

where

$$\bar{\Delta} x_K = \min \left[\frac{x_i}{a_{iK'}}, \ \infty \right], \qquad i \in \boldsymbol{B}', \text{ and } a_{iK'} > 0.$$

$\underline{\Delta} x_K = 0$, as stated, because $x_K = 0$, $K \notin \boldsymbol{B}'$.

(ii) For a change in x_K within the limits given above, in order that the decrease in $C(\mathbf{x})$ may be a minimum, the optimal change in the values of the variables is given by:

$$\Delta x_i = \begin{cases} -a_{iK'} \Delta x_K, & i \in \boldsymbol{B}' \\ 0, & i \notin \boldsymbol{B}' \text{ and } i \neq K \\ \Delta x_K, & i = K \end{cases}$$

(iii) The corresponding change in the value of the criterion function is given by:

$$\Delta C(\mathbf{x}) = w_{K'} \Delta x_K.$$

Algorithm 4b. Change in x_I, $I \in \boldsymbol{B}'$, i.e., x_I is a basis variable in the final tableau.

(i) When a basis variable is changed, a non-basis variable x_K must be increased, as shown in the proof of the algorithm later. To find K proceed as follows:
Let

$$\mu_k = \frac{-w_{k'}}{|a_{Ik'}|}.$$

Evaluate μ_k for every $k \notin \boldsymbol{B}'$ and $a_{Ik'} < 0$ in the case of increase in x_I, and for every $k \notin \boldsymbol{B}'$ and $a_{Ik'} > 0$ in the case of decrease[3] in x_I. Let $\mu_K = \min \mu_k$. (If there are more than one min μ_k, select any one of them.) Then x_K is the non-basis variable that must be increased to give minimum reduction in $C(\mathbf{x})$.

The maximum possible change in x_I, without necessitating a change of basis, is then given by:

$$\underline{\Delta} x_I \leqq \Delta x_I \leqq \bar{\Delta} x_I,$$

where

$$\underline{\Delta} x_I = \max \left[-\frac{x_i a_{IK'}}{a_{iK'}} \right], \qquad i \in \boldsymbol{B}' \text{ and } a_{iK'} > 0,$$

and

$$\bar{\Delta} x_I = \min \left[-\frac{x_i a_{IK'}}{a_{iK'}} \right], \qquad i \in \boldsymbol{B}' \text{ and } a_{iK'} > 0.$$

(ii) For a change in x_I within the limits mentioned above in order that the decrease in $C(\mathbf{x})$ may be a minimum, the change necessary in the values of the variables is given by:

$$\Delta x_i = \begin{cases} -\dfrac{\Delta x_I}{a_{IK'}}, & i = K \\ 0, & i \notin \boldsymbol{B}' \text{ and } i \neq K \\ \dfrac{a_{iK'} \Delta x_I}{a_{IK'}}, & i \in \boldsymbol{B}'. \end{cases}$$

(iii) The corresponding change in the criterion function is given by:

$$\Delta C(\mathbf{x}) = -\frac{w_{K'} \Delta x_I}{a_{IK'}}.$$

Illustration

In the problem given earlier, if at least 10 pieces of product *1* must be produced, from Algorithm 4a, it is easily seen that $\Delta x_3 = -4$, $\Delta x_2 = -14$, and $\Delta x_6 = 14$. $C(\mathbf{x})$ will then decrease by 20, which is the minimum possible decrease in $C(\mathbf{x})$ if the additional restriction $x_1 \geqq 10$ is to be satisfied.

On the other hand, if x_2 must be increased by 18, from Algorithm 4b, we must have $\Delta x_4 = 30$, $\Delta x_3 = -12$ and $\Delta x_6 = -18$. The corresponding decrease in $C(\mathbf{x})$ is 60

CONCLUSION

An important aspect of solution to many practical problems is a sensitivity analysis in order to evaluate the consequences of a change in a constant or of deviating from the optimal solution. From the study presented in this article it is clear that in the case of linear programming problems such an analysis can readily be made using the final simplex tableau. The algorithms presented earlier provide a convenient method of carrying out sensitivity analyses with relatively simple hand-computations even though the original problem may involve such a large number of variables as to necessitate the use of a computer to obtain the original solution.

MATHEMATICAL DEVELOPMENT

We now proceed to give the mathematical justification for the various algorithms given earlier.

Algorithms 1a and 1b

It may be recalled that a tableau in the simplex pro-

[3] If there is no $a_{Ik'}$ satisfying this condition, then x_I cannot be increased or decreased, as the case may be, without violating one of the restrictions. $|a_{Ik'}|$ denotes absolute value of $a_{Ik'}$.

cedure is a solution tableau only if we have $(w_j'+\Delta w_j') \geqq 0$, $j=1, \cdots, m+n$. Algorithms 1a and 1b follow directly from this requirement.

Algorithm 2

Consider the columns $j \in \boldsymbol{B}'$ in the final tableau. Rearrange them to form an identity matrix. Let the corresponding columns $j \in \boldsymbol{B}'$ in the initial tableau also be simultaneously rearranged in the same order. The $m \times m$ matrix thus obtained will be denoted by matrix $\boldsymbol{A}$.

Now consider the columns $j \in \boldsymbol{B}$ in the initial tableau, and rearrange them (if necessary) to form an identity matrix. It can be proved that the $m \times m$ matrix formed by rearranging the corresponding columns $j \in \boldsymbol{B}$ of the final tableau in the same order, will give $\boldsymbol{A}^{-1}$, the inverse matrix of $\boldsymbol{A}$.

Thus, in the illustrative problem, we have:

$$\boldsymbol{A} = \begin{bmatrix} 4 & 1 & 0 \\ 3 & 2 & 0 \\ 0 & 1 & 1 \end{bmatrix} \quad \text{and} \quad \boldsymbol{A}^{-1} = \begin{bmatrix} .4 & -.2 & 0 \\ -.6 & .8 & 0 \\ .6 & -.8 & 1 \end{bmatrix}.$$

It can further be shown that every column in the *body* of the final tableau (shown in heavy lines in Table 3) can be obtained by multiplying on the left (according to the row by column rule of matrix multiplication), the corresponding column in the initial tableau by $\boldsymbol{A}^{-1}$. In particular, if we denote the column in the initial tableau with elements b_i by $\boldsymbol{b}$, (an $m \times 1$ matrix,) and the corresponding column in the final tableau by matrix $\boldsymbol{b}'$ (with elements b_i'), we have

$$\boldsymbol{b}' = \boldsymbol{A}^{-1}\boldsymbol{b}, \qquad \text{Eq. 3.}$$

which can be written as:

$$\boldsymbol{b} = \boldsymbol{A}\boldsymbol{b}'. \qquad \text{Eq. 4.}$$

From the rule of matrix multiplication it is evident that changing an element b_I of $\boldsymbol{b}$ will change the elements b_i' of $\boldsymbol{b}'$ by

$$\Delta b_i' = a_{iI}'\Delta b_I, \qquad i \in \boldsymbol{B}', \qquad \text{Eq. 5.}$$

where a_{iI}' is the element in column I of $\boldsymbol{A}^{-1}$ (i.e., the column corresponding to the variable x_I).

Now consider the equation corresponding to row i, $i \in \boldsymbol{B}'$, in the final tableau. It can be written as:

$$\sum_{j \notin \boldsymbol{B}'} a_{ij}'x_j + x_i = b_i', \qquad i \in \boldsymbol{B}'. \qquad \text{Eq. 6.}$$

But $x_j = 0$, $j \notin \boldsymbol{B}'$. Hence, we have:

$$x_i = b_i', \qquad i \in \boldsymbol{B}'. \qquad \text{Eq. 7.}$$

It may be noted that in the simplex procedure the value of a non-basis variable in the solution tableau is zero. Since the change in b_I under consideration is such that the basis is not changed, the new optimal values of the non-basis variables must still be zero. Hence, when b_i' is changed by $\Delta b_i'$, Eq. 6. gives:

$$x_i + \Delta x_i = b_i' + \Delta b_i', \qquad i \in \boldsymbol{B}'. \qquad \text{Eq. 8.}$$

Subtracting Eq. 7. from Eq. 8. and changing the subscripts from i to j, we have:

$$\Delta x_j = \Delta b_j' = a_{jI}'\Delta b_I, \qquad j \in \boldsymbol{B}'. \qquad \text{Eq. 9.}$$

This proves step (ii) of the algorithm. Step (i) follows directly from the requirement that we must have $(x_j+\Delta x_j) \geqq 0$, $j=1, \cdots, m+n$.

We now consider the change in the value of the criterion function. From $C(\mathbf{x}) = \sum_j c_j x_j$, we have:

$$\Delta C(\mathbf{x}) = \sum_{j \in \boldsymbol{B}'} c_j \Delta x_j,$$

as only the basis variables are changed. Substituting from Eq. 9., we have:

$$\Delta C(\mathbf{x}) = \sum_{j \in \boldsymbol{B}'} c_j a_{jI}'\Delta b_I = \Delta b_I z_I',$$

which completes the proof.

Algorithm 3a

Let an element a_{IJ}, $J \in \boldsymbol{B}'$, be changed by Δa_{IJ}. $J \in \boldsymbol{B}'$ implies that a_{IJ} is an element of matrix $\boldsymbol{A}$ defined earlier. Hence, denoting the new matrix (with one element a_{IJ} of $\boldsymbol{A}$ changed by Δa_{IJ}), by $\bar{\boldsymbol{A}}$, we have:

$$\begin{aligned} \bar{\boldsymbol{A}} &= \boldsymbol{A} + \Delta a_{IJ}\boldsymbol{E} \\ &= \boldsymbol{A}[I + \boldsymbol{A}^{-1}\Delta a_{IJ}\boldsymbol{E}], \end{aligned}$$

where $\mathbf{E}$ is an $m \times m$ matrix with a unit element at row I and column J and zero elsewhere, and $\mathbf{I}$ is an $m \times m$ identity matrix. Hence,

$$\bar{\boldsymbol{A}}^{-1} = [I + \boldsymbol{A}^{-1}\Delta a_{IJ}\boldsymbol{E}]^{-1}\boldsymbol{A}^{-1}.$$

The new value of $\boldsymbol{b}'$ is therefore given by:

$$\boldsymbol{b}'' = \bar{\boldsymbol{A}}^{-1}\boldsymbol{b} = [I + \boldsymbol{A}^{-1}\Delta a_{IJ}\boldsymbol{E}]^{-1}\boldsymbol{b}', \qquad \text{Eq. 10.}$$

as $\boldsymbol{A}^{-1}\boldsymbol{b} = \boldsymbol{b}'$ from Eq. 3. It can be shown that

$$[I + \boldsymbol{A}^{-1}\Delta a_{IJ}\boldsymbol{E}]^{-1} = [I + \boldsymbol{A}^{-1}\sigma_{IJ}\boldsymbol{E}], \qquad \text{Eq. 11.}$$

where

$$\sigma_{IJ} = \frac{-\Delta a_{IJ}}{1 + \Delta a_{IJ}a_{JI}'},$$

a_{JI}' being the element in row J and column I of $\boldsymbol{A}^{-1}$, i.e., the element at the intersection of x_J's row and x_I's column in the final tableau. Substituting Eq. 11. in Eq. 10., and subtracting $\boldsymbol{b}'$, we get:

$$\begin{aligned} \{\Delta b_i'\} = \boldsymbol{b}'' - \boldsymbol{b}' &= [I + \boldsymbol{A}^{-1}\sigma_{IJ}\boldsymbol{E} - I]\boldsymbol{b}' \\ &= \boldsymbol{A}^{-1}\sigma_{IJ}\boldsymbol{E}\boldsymbol{b}'. \end{aligned}$$

It can be easily verified that $\boldsymbol{A}^{-1}\sigma_{IJ}\boldsymbol{E}$ is a matrix with elements

$$p_{ij} = \begin{cases} a_{iI}'\sigma_{IJ} & \text{when } j = J \\ 0 & \text{when } j \neq J. \end{cases}$$

Therefore, $A^{-1}\sigma_{IJ}Eb'$ is an $m\times 1$ column matrix with elements $a_{iI}'\sigma_{IJ}b_J'$, and the change in the elements of b' is given by:

$$\Delta b_i' = a_{iI}'\sigma_{IJ}b_J' = -\frac{\Delta a_{IJ}a_{iI}'x_J}{1+\Delta a_{IJ}a_{JI}'}, \qquad i \in B'.$$

In the proof of Algorithm 2 it was shown that when b_i' is changed by $\Delta b_i'$, the optimal change in the values of the variables is given by:

$$\Delta x_i = \begin{cases} \Delta b_i', & i \in B' \\ 0 & i \notin B'. \end{cases}$$

Substitution of the value of $\Delta b_i'$ gives step (ii) of the algorithm. Substituting the value of Δx_i, $i\in B'$, in the relation

$$\Delta C(x) = \sum_{i\in B'} c_i\Delta x_i,$$

gives step (iii) of the algorithm, since

$$\sum_{i\in B'} c_i a_{iI}' = z_I'.$$

To prove step (i) of the algorithm, consider the change in w_j'. When a_{IJ} is changed by Δa_{IJ}, it can be shown that the corresponding change in a_{ij}' is given by:

$$\Delta a_{ij}' = \begin{cases} 0 & i,j \in B', \\ a_{iI}'\sigma_{IJ}a_{Jj}', & i \in B' \text{ and } j \notin B'. \end{cases}$$

The change in w_j' is, therefore, given by:

$$\Delta w_j' = \begin{cases} 0, & j \in B' \\ -z_I'\sigma_{IJ}a_{JI}', & j \notin B'. \end{cases}$$

Step (i) then follows from the requirement that we must have

$$(x_i + \Delta x_i) \geqq 0 \text{ and } (w_j' + \Delta w_j') \leqq 0, \qquad i,j = 1, \cdots, m+n.$$

Algorithm 3b

In this case, we change a_{IJ}, $J \notin B'$. Hence, the matrices A and A^{-1} are unchanged. Since every column of the final tableau is obtained by multiplying the corresponding column of the initial tableau by A^{-1} (as pointed out before), only column J of the final tableau will be affected by a change in a_{IJ}. The change in a_{iJ}' is given by:

$$\Delta a_{iJ}' = \Delta a_{IJ}a_{iI}', \qquad i \in B'.$$

This will change z_J' by:

$$\sum_{i\in B'} c_i(\Delta a_{IJ}a_{iI}') = \Delta a_{IJ}z_I',$$

and will change w_J' by $-\Delta a_{IJ}z_I'$.

It is clear that the final tableau is a solution tableau so long as we have $(w_J' - \Delta a_{IJ}z_I') \leqq 0$, from which Algorithm 3b follows.

Algorithm 4a

Let x_K, $K \notin B'$. be increased by Δx_K. (x_K cannot be decreased as its value is zero.) Suppose that in order to get a minimum reduction in $C(\mathbf{x})$, the changes in the values of the variables be such that:

$\Delta x_j > 0$ when $j \in S_1$, where $S_1 \subset B'$, and

$\Delta x_k > 0$ when $k \in S_2$, where $S_2 \subset \{k \mid k \notin B'\}$.

We now proceed to show that for an optimal change, $S_1 = \{i \in B' \mid a_{iK}' \neq 0\}$, and $S_2 = \{K\}$.

Consider Eq. 6. and Eq. 7. corresponding to row i in the final tableau. When x_K is changed, Eq. 6. gives:

$$\sum_{k\in S_2} a_{ik}'\Delta x_k + x_i + \Delta x_i = b_i', \quad i \in S_1, \text{ and} \qquad \text{Eq. 12.}$$

$$\sum_{k\in S_2} a_{ik}'\Delta x_k + x_i = b_i', \quad i \in (B' - S_1), \qquad \text{Eq. 13.}$$

where $(B' - S_1)$ denotes the set containing the elements of B' but not of S_1.

Subtracting Eq. 7. from Eq. 12. and Eq. 13. respectively, we have:

$$\sum_{k\in S_2} a_{ik}'\Delta x_k + \Delta x_i = 0, \quad i \in S_1, \text{ and} \qquad \text{Eq. 14.}$$

$$\sum_{k\in S_2} a_{ik}'\Delta x_k = 0, \quad i \in (B' - S_1). \qquad \text{Eq. 15.}$$

Now consider the value of the criterion function. The change in $C(\mathbf{x})$ is given by:

$$\begin{aligned} \Delta C(\mathbf{x}) &= \sum_{i\in S_1} c_i\Delta x_i + \sum_{k\in S_2} c_k\Delta x_k \\ &= -\sum_{i\in S_1} c_i \sum_{k\in S_2} a_{ik}'\Delta x_k + \sum_{k\in S_2} c_k\Delta x_k \end{aligned} \qquad \text{Eq. 16.}$$

by substituting for Δx_i from Eq. 14. From Eq. 15. we have:

$$\sum_{i\in(B'-S_1)} c_i \sum_{k\in S_2} a_{ik}'\Delta x_k = 0. \qquad \text{Eq. 17.}$$

Adding Eq. 16. and Eq. 17., we get:

$$\begin{aligned} \Delta C(\mathbf{x}) &= -\sum_{i\in B'} c_i \sum_{k\in S_2} a_{ik}'\Delta x_k + \sum_{k\in S_2} c_k\Delta x_k \\ &= -\sum_{k\in S_2} \Delta x_k \sum_{i\in B'} c_i a_{ik}' + \sum_{k\in S_2} c_k\Delta x_k \\ &= \sum_{k\in S_2} (c_k - z_k')\Delta x_k = \sum_{k\in S_2} w_k'\Delta x_k. \end{aligned} \qquad \text{Eq. 18.}$$

This can be written as:

$$\Delta C(\mathbf{x}) = w_K'\Delta x_K + \sum_{\substack{k\in S_2 \\ k\neq K}} w_k'\Delta x_k.$$

In the foregoing equation Δx_K is the change in x_K under consideration. It is clear that $\Delta C(\mathbf{x})$ is a minimum when the second term in the above expression vanishes, i.e., when $S_2 = \{K\}$. The minimum value of $\Delta C(\mathbf{x})$ is then given by $w_K'\Delta x_K$ which proves step (iii) of Algorithm 4a.

Now consider Eq. 15. To satisfy this when $S_2 = \{K\}$, we must have $a_{iK}' = 0$, $i \in (B' - S_1)$, i.e., $S_1 = \{i \in B' \mid a_{iK}'$

$\neq 0\}$. From Eq. 14. and Eq. 15. we then have:

$$\Delta x_i = -a_{iK}'\Delta x_K, \quad i \in B', \qquad \text{Eq. 19.}$$

which completes the proof of step (ii) of the algorithm. Step (i) follows from the non-negativity requirement for each x_i.

Algorithm 4b

Let x_I, $I \in B'$, be changed by Δx_I. It can be shown that Eq. 12. through Eq. 19. given in the proof of Algorithm 4a hold in this case also. For $i = I$, Eq. 14. gives:

$$\sum_{k \in S_2} a_{Ik}'\Delta x_k + \Delta x_I = 0. \qquad \text{Eq. 20.}$$

When x_I is changed, in order to satisfy this equation, we must increase at least one x_k, $k \in S_2$. Further, from Eq. 18., since $(c_k - z_k') \leqq 0$, $k \in S_2$, the minimum value of $\Delta C(x)$ is obtained when only one non-basis variable (call it x_K), is increased, i.e., we must have $S_2 = \{K\}$. We now proceed to show how this element can be identified. Letting $S_2 = \{K\}$ in Eq. 20. we get:

$$\Delta x_K = -\frac{\Delta x_I}{a_{IK}'}. \qquad \text{Eq. 21.}$$

Letting $S_2 = \{K\}$ in Eq. 18., and substituting for x_K from Eq. 21. gives:

$$\Delta C(x) = -\frac{w_K'\Delta x_I}{a_{IK}'}.$$

Now consider Eq. 20. Δx_K is positive since x_K cannot be decreased. Hence, we must have $a_{IK}' < 0$ when $\Delta x_I > 0$, and $a_{IK}' > 0$ when $\Delta x_I < 0$. The rule given at step (i) of the algorithm, therefore, insures that we get the minimum value of $\Delta C(x)$. The equations for evaluating $\overline{\Delta x_I}$ and $\underline{\Delta x_I}$ follow from the requirement that we must have $(x_i + \Delta x_i) \geqq 0$.

Now consider Eq. 15. To satisfy this when $S_2 = \{K\}$, we must have $a_{iK}' = 0$, $i \in (B' - S_1)$. Hence, from Eq. 14. and Eq. 15., substituting for Δx_K from Eq. 21., we have:

$$\Delta x_i = \frac{a_{iK}'\Delta x_I}{a_{IK}'}, \qquad i \in B',$$

which completes the proof.

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The Art of Methods Engineering*

by **CECIL W. GUYATT**

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YOUR president has pointed out that the membership of this society is primarily interested in furthering Industrial Engineering as a well recognized and regarded profession. He and I agreed upon methods engineering, one of the basic functions of Industrial Engineering, as the general topic. We felt that a technical discussion might cover an already much traveled road. Our specific subject was chosen as we recalled the situation of a mutual acquaintance.

This man has an excellent educational record and a substantial background of Industrial Engineering experience. Some time ago this man was appointed to a responsible management position in charge of the methods engineering function of a large plant.

He told me one day that he didn't know why he wasn't getting better performance. He had a well organized department, staffed with competent personnel and all the means for sound work assignment and evaluation of performance. Despite these favorable conditions, this aggressive and ambitious individual was not fully satisfied with the results of his efforts.

THE ARTFUL TOUCH

The real cause of his dissatisfaction was not self-evident. But as the problem was explored, it seemed that in his drive to apply the tools of methods engineering, he had forgotten that the application of this management science requires an artful touch. This deficiency was the root of his inadequate performance.

Our recollection of these circumstances led to the conclusion to emphasize the importance to successful methods engineering of the "artful touch."

That art enters into the conduct of methods engineering may be a novel idea to some of you. It may be a temptation casually to dismiss the idea as being only a theoretical concept. Do not underestimate this point! The lack of the artful touch may mean the difference between success and failure in any program for installing effective manufacturing practices.

* Based upon a presentation to the Pittsburgh Chapter, American Institute of Industrial Engineers, March 4, 1959.

Of course, it is important to know about the tools of methods engineering. Much has been written and said about flow diagrams, process charts, work sampling and the other technical aids for methods analysis. Acquiring familiarity with these tools is a relatively simple matter of study and practice. The application of these tools for appropriate solutions in a particular situation is also a simple matter of applying engineering skill and common sense.

No one would use a large computer to add up a few items on an invoice, nor a pocket knife to fashion an elaborate foundry pattern. Neither would a competent Industrial Engineer attempt to devise methods that have no application, nor to solve a methods problem with a solution so complex that no one concerned with its use could understand it or apply it.

So it is important to learn how to use the tools of methods engineering as well as to know about the tools themselves. But such knowledge and skill is far from sufficient if a methods engineering group in a plant is to conduct a long term program that is regularly marked with the installation of effective manufacturing practices.

Actually, methods work is an unusual field of engineering. No method is made effective except through the thinking and doing of people. It not only involves engineering analysis and design, it also must take into account the aptitudes and motivation of people.

Methods engineering usually functions under a continuing demand from top management for significant cost reduction which in the final analysis is made effective through the efforts of front line supervision. These supervisors naturally are first concerned with product quality, meeting daily production quotas and maintaining sound working conditions and harmonious working relations. While they may be interested in cost reduction, they also fear criticism for exposed inefficient methods and disturbance to their routine as a result of methods engineering activity.

Methods engineering to be fully effective must make use of the knowledge and services of the other staffs in a plan, and, because of the kind of projects, methods engineering frequently serves as coordinator for various involved staff activities. Again, such work must be done by treading delicately beween differing opinions as to what should be done by whom and inherent fear about misplacement of credit for results accomplished.

There are other aspects of methods engineering that could be cited along these same lines. But, I believe it should be clear by now that the conduct of methods engineering inevitably must go forward under conditions that reflect the reactions of human beings under many varied circumstances. These reactions sometimes are passive and at other times positive or negative. The causes are usually complex and difficult to understand because the thinking and behavior of people is not subject to rigid laws. Nevertheless, successful methods engineering needs conditions of favorable reactions and this requires an awareness of the causes of human behavior and the possession of some knowledge and skill to manipulate them.

We can now make our major point. The technical tools of methods engineering can be readily acquired, but the creation of conditions favorable to effective application which is equally important is frequently more difficult to achieve. Ability in this latter phase is more an art than application of a science.

I suspect that in our various society meetings and writings we have not sufficiently emphasized that methods engineering must rest squarely on both science and art. Unbalance means inadequacy. So, to those who look at our work solely from the science viewpoint and sneer at the need for the artful touch, I suggest a careful self-appraisal of their actual position.

The acquisition of the artful touch is not easy. It is said that some people are born with the ability to work harmoniously and effectively with fellowmen. That may be true, but no staff or department of a plant springs into being with such ability. Undoubtedly any existing staff was created by top management to meet a need. But that fact does not guarantee that the staff will effectively meet the need. Nor does it guarantee that the staff will acquire automatically the necessary artful touch. It requires study, plans and action.

It is tempting to look at this problem in terms of the individuals who make up a methods engineering staff. It is easy to assume that given individuals with skill in human relations, the problem of the staff as an entity is solved. Yet under this assumption with training steps taken we have gone only half-way to what is necessary.

ENVIRONMENT

Actually, for the staff, we are concerned with creating and maintaining an environment within the staff and within the plant as a whole that facilitates, not hinders, the installation of methods improvements. It is an environment that is characterized by a feeling of mutual respect between methods engineering and the other organization segments of the plant. It is an environment where the true function of methods engineering is understood and all necessary outside assistance to problem solution is willingly offered without particular concern about the credit for the final solution. It is an environment where methods engineering is freely consulted by other functions where their work bears on the interest of methods engineering. Finally, it is an environment where the accomplishments of the methods group are at least as well remembered as the failures.

I think I can guess what your reaction is to these specifications. Probably you have tagged them as ideals and impractical for full accomplishment. If so, you are right. But ideals are as necessary to a staff as is a compass to a ship. For the staff, like the ship, if you point

it toward the desired destination, you may have some troubles with the voyage, but you will at least have an excellent chance of approaching your desired destination.

It is true that there are a number of factors that affect environment. Many of them are interrelated. We can only touch on a few major ones as they concern a typical methods group of any plant. And in doing this we must remember that this group is in the plant because of top management direction to meet important needs. Further, we must assume for the methods group:

1. That responsibility and authority are clearly specified and approved by all controlling and concerned elements of management.
2. That the short and long range needs to be met by the methods group are established in order of priority, approved by concerned management and with provision for constant adjustment to fit current conditions.
3. That an up-to-date plan of action is always available to meet the established needs.
4. That there is adequate competent technical personnel to carry out the plan of action.
5. That there is competent technical administration with means for sound assignment of work, follow-up and audit of results.

A methods group without all of these conditions of organization is basically deficient and there may be little purpose served by concern with environment.

Psychologists tell us that environment associated with people is the result of two influences: that which we cause and that which is caused by others. Each influence is of course affected by the other. But it is possible and convenient to consider each separately.

The influence of the methods group in affecting environment is by far the most important. Many factors affect this influence. Of those that might be cited, I propose to briefly discuss only three:

1. Morale
2. Flexibility
3. Leadership

MORALE

I place morale first because it is the most important. Without morale there is little chance of securing the cooperation of others, of gaining respect and accomplishing results. Morale is the prevailing mood and spirit conducive to willing and dependable performance and determined conduct despite difficulties. It is based on a conviction of being in the right and on the way to success with faith in the program.

The methods group with morale is especially marked by a spirit of wholehearted cooperation in a common effort. The majority of the members are really enthusiastic and dedicated to their profession. And their efforts are constantly pointed, on an undiluted basis, to the good of the company.

Thus, morale rules out the building of a group empire. It rules out individuals who seek flashy individual performance and glory while neglecting the over-all needs of teamwork. It rules out those who are unwilling to build up friendly constructive relationships throughout the plant on the basis of objectivity and integrity.

The various plant groups, outside of methods, are quick to sense morale. And as psychologists point out they respond constructively with an attitude of respect.

Morale must be worked for and earned. It never just happens. It is a kind of reserve that must be continuously replenished and strengthened. It cannot be built just when it is most needed. So, I suggest that each of you should be a student of the art of morale building and promptly take the steps necessary to practical application.

FLEXIBILITY

Our second factor is flexibility. All of the factors that influence environment are important, but here is one that is almost indispensable to success. Many an organization has failed because it was not adaptable to changing conditions or regarded its procedures as the only sound way.

We spoke earlier about our technically competent supervisor with excellent organizational arrangements. You will recall that he was not fully satisfied with his efforts. Some of his trouble stemmed from his rather inflexible attitude which naturally was reflected by his group in all of their plant contacts. The procedures of the group established carefully at one time were ironbound and under these, solutions to proposed problems were considered to be the only right ones. As a result constructive thinking in light of new conditions was actually inhibited. Sometimes solutions to plant problems were sound, but many times they were not when looked at from the view of prevailing conditions. So, the methods group was regarded by some in the plant as an impractical organization and by others as obstinate. And our supervisor finds his organization working under a load of difficulties and attaining inadequate performance.

The Aesop fable about the oak and the reed is pertinent to the problem of inflexibility. In the fable the oak, by resisting the wind is broken. The reed, flexing with each gust is still intact in the morning.

There's a difference between perseverance and obstinacy. Like the oak in the fable, the obstinate organization is broken due to its inflexibility, even though it rationalizes its attitude as being "strength of character" or a reflection of "sound engineering." But the persevering organization steadfastly and soundly pursues its aims in spite of difficulties.

A flexible organization is noted for its open-mindedness. It keeps its own thinking procedures soundly adaptable to current conditions. It is prompt to admit mistakes as a sign of maturity and bigness.

If the attitude of a methods group reflects all these things it will gain the respect and cooperation of all groups in the plant. And it will be regarded as progressive with no assumed air of superiority.

So, there is real strength in flexibility. The manipulation of thinking, for its accomplishment is an art. And it warrants your best efforts.

LEADERSHIP

The third factor we want to briefly discuss is leadership. Here we arrive upon ground that has been frequently plowed and harrowed. Most often this subject is taken up with what may be called a "high level" approach. For our present purposes, we can note one major conclusion of this approach which is of considerable importance. It is simply that leadership if assigned is never really effective unless it is earned. And in this discussion about leadership we are referring, of course, to the field of developing new methods for installation.

For such leadership it is essential that the mannerism of the methods group and the personalities of the individuals making up the group be pointed toward building up friendly relationships with the departments to be served. This has to be done on the basis of objectivity and integrity. Yet, sometimes this is a most difficult thing to do because the temptations for an engineer to rationalize conclusions desired by operators are great at times. Only a soundly oriented mental attitude and its consistent application makes it possible.

Leadership requires that the methods group be pointed in the direction of meeting plant needs in the most effective manner. It is very easy for the group, and the individuals therein, to yield to the temptation of riding pet projects or to serve the client who is most demanding with needs that are inconsequential. It is most tempting to forget maintenance needs in connection with past services to do more sensational things or to do things which come naturally without headaches. It is equally tempting to acquire a "paper work" attitude in which non-productive effort on paper becomes an end in itself. Other groups of a plant are quick to sense any yielding to these temptations. When they do so, leadership may be lost and recovered only with great effort.

That brings us up to what is perhaps the most important element of leadership. Most certainly, the methods group must be creative and resourceful. Among other things it must bring in new applicable ideas from outside the company and serve as the catalyst in making them applicable. In doing this, the groups promotional efforts should be with a good sense of timing so as not to dissipate energy by being premature, or fail the company by being too late.

Being creative and resourceful does require a group made of individuals with inherent ability. But its expression requires receptive and outgoing minds and an attitude of the methods group that expects and cultivates creativeness and resourcefulness. This attitude when backed up by performance invariably commands respect throughout the plant and leadership is a natural result. The cultivation of a sound attitude for leadership, as with morale and flexibility is an art which if neglected will lead only to a loss of professional status and ineffective performance.

SUMMARY

So there you have a brief story about three factors—morale, flexibility and leadership which I consider to be the most important considerations when we talk about the influence of the methods group in affecting environment. And that brings us down to the influence on plant environment of others outside of the methods group. This is important because we know that others can favorably and unfavorably affect the environment in which we operate.

It is a common complaint by methods engineers that "they"—speaking of course about everyone but themselves—do not appreciate the real value of their services nor do they make use of their abilities in the proper fashion. Frequently in such cases, a magic formula is sought that will in one easy step create favorable attitudes throughout the plant. The formula used sometimes involves seeking executive rulings or a publicity and selling campaign.

Of course it is important to have executive backing on basic matters. It may be necessary from time to time to conduct a publicity or selling campaign. It is essential that effective channels of communication be established and maintained. It is important that the methods group:

1. Be forthright in explanations as to purpose of the work being done.
2. Always give credit where credit is due.
3. In all contacts with plant associates it is clear that an individual is truly regarded as a human being—not as an inanimate object—and treated with dignity as a person.

These things affect the attitudes of other groups in the plant. But the real answer to our basic problem must come from the methods group for a reason that I hope is almost self-evident by this time.

The attitudes of other groups in a plant are in the main a reflection of the attitudes of the methods group. The respect shown for the methods group throughout the plant is mostly governed by demonstrated ability to meet plant needs.

So, if we want a favorable plant environment it has to be earned. That is the hard fact. Under sound conditions of organization structure, the earning is done by our skill in establishing in the methods group attitudes of morale, flexibility and leadership. And all of this is art of a high order. We need more of it in methods engineering.

Few artists in any field are born. Most must be made. The art in methods engineering, like any other art, must be developed by practice, by analyzing the success of others and by continuous conscientious study of our own situations. It is hard work. But the results can be ample reward.

Industrial Administration: Education for 1980*

by **G. L. BACH**

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OVER the past decade, it seems clear that two significant changes are occurring in Industrial Engineering. First, it has become less descriptive and how-to-do-it oriented, and more fundamentally analytical. This has involved greater introduction of statistics and modern mathematics, and many of the tools of "operations research." Second, it has introduced more of a management viewpoint, especially in the production and manufacturing area, but extending beyond this.

Over the same period, major modifications have been introduced at leading graduate business schools. These, too, have involved increasing emphasis on analysis in contrast to descriptive, how-to-do-it approaches. They, too, have looked increasingly toward fundamental training for management, in contrast to narrow specialization in the particular functional fields of business.

At a few universities, a new approach, often called "industrial administration" or "industrial management," has been taken. It begins without the ties to the past of either Industrial Engineering or business administration, and builds directly on the presumption that the major goal is to train men for managerial responsibilities in the world of 1980—where the role of careful, rational analysis will bulk large, where management will increasingly need to utilize effectively modern technology, and where managerial problems will be ever changing, and far different from those we recognize today.

My purpose is to present the rationale underlying one such new program in industrial administration—the Graduate School of Industrial Administration at Carnegie Tech—and briefly the educational approach to which it has led. I do not wish to imply, of course, that this is "the" kind of education for the future. But, I venture to hope that it may be of some interest to you, particularly as it relates to the changing nature of Industrial Engineering.

TRAINING FOR CHANGE

My first proposition is that the universities are training men for the world of the 1980's, and that we ought to face up to this fact. In 1980, most present college students will be only about 40, with over half of their professional lives still before them. To train men primarily for the 1960's is to miss most of the problem. To focus even on the 1970's is to concentrate on the first quarter of our students' professional careers. The world of the 1980's—terrifyingly far away as it may seem—thus provides a goal only about midway through the careers of our present students.

When our school of Industrial Administration was established in 1949, we spent a year trying to face up to this fact. We talked to everyone we could find, we looked at professional education in widely differing fields, and we read. What were our conclusions?

First, although no one knows what the industrial world of 1980 will look like, I am sure of one thing. It, and the rest of the world, will change greatly over the next quarter of a century. Edward Teller, the famous physicist, has stated recently that in the century since 1850 man has roughly doubled his knowledge of the world and of mankind in the world. While any such observation must be extremely rough, it suggests the enormous accumulation of knowledge that has been taking place in the last three centuries. If Teller is right, in knowledge of human behavior we will learn more about man and his behavior in the next century than in all previous history. Today's newspaper accounts of fantastic space age developments make this prediction increasingly believable. What most people don't realize is that a similar explosion may be under way in our knowledge of man and his managerial behavior.

Given the certainty of change and the uncertainty of its direction and outcome, it seems to me clear that we must place central importance on our university training —for administration in industry, as elsewhere—on students' thought processes and not on particularized subject matter. In such a world, surely anything we can do to develop flexibility of mind, openness and receptivity to new and changing ideas, habitual skills in learning for oneself, and other such mental characteristics, must promise more usefulness to the individual and to society over the quarter century of change ahead, than would comparable attention to descriptive information about to-

* Based upon a presentation to the Industrial Engineering Section of the American Society for Engineering Education in June, 1959.

day's institutions and today's best industrial practice. It suggests equally that we must emphasize fundamental analytical tools, reaching for those of broad and general applicability, with emphasis on how to use them effectively in widely varying situations, rather than on detailed particular skills and techniques.

DIRECTIONS OF CHANGE

This is the main conclusion we reached. But beyond this, I suggest that we do have a good deal of evidence about some of the major directions of change. What are some of these?

1. Management will become ever more rational and analytical, and the role of "hunch" and even "informed judgment" will become steadily smaller as the years go by. Mathematical programming, queueing theory, statistical decision theory, and other such tools will be commonplace in the industry of 1980, and the effective manager will have to know how to use them, just as he must now know how to use the contributions of modern engineering and science. To focus too heavily on particular analytical approaches would be a mistake, however. The critical change will be the increase in the clarification of the variables that need to be considered in making industrial decisions, the increase in the use of carefully obtained quantitative information as to these variables, and the increase in the use of rigorous analysis in weighting and combining the variables involved. We all know that in some vague intuitive way this is what we must be doing when we make decisions now. The change I am predicting is, therefore, one of clarifying and bringing to the surface the variables and implicit logical models our minds must now be using in decision-making, plus a big improvement in the logic of the models and their methods.

I want to emphasize that I am not referring merely to decisions in the production and manufacturing areas, where such methods have thus far been most generally applied. One of the biggest advances is, I believe, going to be the extension of such thinking throughout the entire range of management decision making.

2. Increased emphasis will be placed on the job of management, or administration, *per se*, especially in the bigger companies. Management must make decisions, and it must get the decisions (plans and policies) carried out effectively. The need for effective administration, *per se*, has been emphasized many times in recent years, and there is no need to labor it here. It is related to the growing size and complexity of business in all of its elements, to the greater need for conscious planning and control, to the growing difficulties of communication in large and complex organizations, and so on. It means less and less willingness to assume that good managers are just born and that there is nothing to do about it except let them develop as they will.

3. The social responsibility of the corporation and of the businessmen in it will bulk ever larger in the day-to-day life of most business firms. Explicit interest in the public good as a legitimate and important immediate goal of business behavior will continue to grow, in contrast to any simple emphasis on short-run profit maximization. Business will participate in a conscious fashion to an increasing extent in the social-economic processes of our democratic society. Business will be judged by the community increasingly on the way in which it participates in these processes, as well as on the older criteria of production and price. The role of the manager, therefore, will increasingly be that of a man with many masters, and it will behoove him to be sensitive to the pulse of the whole community, not merely to what goes on inside his factory walls. He will become increasingly a coordinator of diverse interests and "pulls" in the modern firm and in modern society—in contrast to simply being "the boss," responsible merely to a small group of stockholders.

EDUCATIONAL OBJECTIVES

To us, this analysis pointed strongly toward educational focus on the development of individual abilities to think, to adjust, and to learn independently in a world of change, after leaving the campus. It emphasized, certainly for men who will rise to managerial positions, the importance of becoming prepared to make and implement decisions on unknown problems, with unknown, yet-to-be-developed analytical tools. Our basic educational objective, we said, would therefore be to help each student acquire for himself:

1. *Competence in the orderly, analytical exploration and handling of problems.* Ability to identify, to size up, and to deal effectively with problems wherever they arise is the mark of the able professional man in any field. Development of an habitually orderly, rational approach to problems, in whatever area they arise, is a major goal of our educational program. This competence does not come automatically; it can be taught.

2. *Thorough and integrated understanding of fundamental knowledge in industrial administration.* The educational program emphasizes thorough knowledge, and effective use of that relatively small amount of fundamental knowledge which has *general* usefulness and applicability. This approach emphasizes the job of using basic concepts and principles in defining and handling problems—in contrast to trying to memorize "answers," detailed techniques, and rules of thumb, which are apt to be of little value when new problems arise in the future. These fundamental tools should be drawn from wherever they are available—mathematics, engineering, business, economics, the behavioral sciences. In a world of rapid change, unless the administrator has a firm grasp of fundamental knowledge, concepts, and principles, to serve as a framework in analyzing and handling diverse problems, he will be lost in a maze of facts and details.

3. *The habit of learning from experience, including habitual receptiveness to new ideas and new ways of doing things.* No school can teach more than a small portion of what the successful professional man must know; the rest he must learn for himself through life. In the modern world of rapid change, the man who does not continue to learn and grow is soon consigned to routine tasks. To grow he must observe, listen, and read widely and perceptively, constantly adjusting his thinking and practices in the light of what he learns.

4. *A basis for dealing effectively with other people, both in person and through written communication.* In modern industry, as in every other phase of modern life, ability to work effectively with other people is perhaps the most crucial of all skills. Administrative policy is made and carried out by individuals, working as parts of groups. Thorough understanding of human nature and of individual motivation in group relationships is increasingly essential for successful formation and execution of administrative policies.

5. *Thorough understanding of the economic, political, and social system in which he lives and in which industry operates.* As a man moves upward in industry, he becomes increasingly concerned with the relations between his business and the outside world. Business cycles, labor unions, political developments, taxes—such forces exercise powerful influence on him and on his firm. On grounds of both professional administrative training and responsible citizenship, genuine understanding of the over-all economic and social system is essential, parallel to the training for internal management of industrial affairs.

6. *Independence of thought and maturity of character.* For future managerial growth and for responsible citizenship, each man must develop an ability to reach conclusions *for himself* on a carefully reasoned basis. As a foundation he must develop his own

set of moral and ethical values, and he must recognize the need for working constructively with others who hold different sets of values. Only such a set of personal and social values can provide the foundation of which true independence of thought and maturity of judgment can rest.

It will be clear that this list of fundamental objectives could, with little change, be applied to most other areas of professional education, and this is as it should be. But the fundamental analytical tools developed, and the problem areas investigated, differentiate training for industrial administration from that in other professional fields.

EDUCATIONAL PROGRAM

What kind of educational program can develop these abilities? Carnegie's Graduate School of Industrial Administration provides a two year M.S. program in Industrial Administration specifically for men with undergraduate backgrounds in science, engineering, and mathematics. Each year we accept about fifty such men, mainly headed for managerial careers in industry, where combined training in engineering-science and in management is increasingly in demand. For this group, we have designed the following program. Remember, in this description of specific course areas, that overriding emphasis is placed on the six fundamental objectives indicated previously. Decision-making and getting decisions carried out effectively, plus the tools needed to achieve these goals, provide the organizing focus for the curriculum.

FIRST-YEAR PROGRAM

The first-year program contains three foundation stems and the beginning of application to the functional areas of business.

1. *A foundation stem—"the administrative process and human behavior" (the behavioral sciences).* This stem looks in detail at the firm as a going organization, and at the behavior of human beings as individuals and as groups in it. It draws heavily on the analytical concepts and approaches of the "behavioral sciences," as well as upon what we are beginning to build up in the theory of administration, in understanding these processes. It is concerned not primarily with the traditional descriptive aspects of business firms, but with analytical tools designed to help understand influence processes, motivation, communication processes, and so on in the organization. It is basically a tool stem, but there is heavy emphasis on getting students to apply these tools for themselves in analyzing business situations of all sorts. Unfortunately, the behavioral sciences as they now stand do not provide a large reservoir of immediately useful analytical concepts and models. But there is much there, and more every year. There is still a big job ahead in reforging many of the tools and in building new ones, cooperatively with behavioral scientists, to develop this stem from the modest level at which it must now operate to the crucial position it will surely have as the years go by.

2. *A foundation stem—"quantitative methods and mathematics."* This stem deals with the use of figures in business decision-making and control. It provides new tools of modern mathematics to the extent they are needed, and builds heavily on the available tools of accounting and statistics. The emphasis is not on training accountants or statisticians or mathematicians. Rather it is on the use of these disciplines to help make good managerial decisions and to implement them effectively. With the backgrounds our students have in engineering and science, it is possible to move rapidly in these areas and to make use of many of the modern developments which would not be feasible for regular business school groups. Here, as with the behavioral science foundation stem, there is much work to be done in shaping up the tools of modern quantitative methods so they will be most effective for managerial decision purposes.

3. *A foundation stem —"economic analysis and the environment of business."* Here intensive attention is given to the analytical tools of both micro- and macro-economics. Again, the goal is not to train men as professional economists, but to see that they have a good grasp of the central analytical concepts of modern economics in both areas—the behavior of the business firm as an individual unit in the market economy, and the over-all processes of economic growth and fluctuations. Attention is focused both on managerial applications of these tools and on understanding the functioning of the entire economic system. Repeatedly, for example, on the problem of investment decisions, students are placed in a position of looking at the same situation from a managerial decision-making point of view and from the point of view of its relationship to over-all economic development.

4. *The functional fields of business.* About three-fourths of the time in the first year is devoted to the three stems above. But students cannot learn to use analytical tools effectively without using them. In business, the so-called "functional fields" (production, marketing, and finance) provide the major problem areas for the exercise of decision-making and tool-using ability. Our conception is that these fields are essentially applied problem areas.

Take the production area as one example. Here we want the students to get a good exposure to the major types of problems faced by modern business in the whole area of production. In looking at these problems, we expect him to pick up a good bit of information about the modern world, but this is not the primary objective. Mainly he is asked to analyze problems in the sub-areas of the production function, bringing to bear the tools he is learning throughout the rest of the curriculum. There is not yet in the production area a cohesive discipline of analysis and organized knowledge, and we believe that many of the analytical tools needed can be provided by the three foundation stems above. For example, the modern developments in inventory control and production go back to mathematics and central concepts of economic theory. Getting satisfactory work levels out of production employees is much the same problem as for any other class of employees—here the tools of the behavioral sciences can help in understanding human motivation and response to different types of incentives and pressures. Good analysis of a plant layout problem requires understanding of engineering considerations, economic considerations, and of human considerations, and in all of them information comes largely in quantitative form. An optimal plant location decision requires, again, analysis using all the above tool areas, unless one is prepared to go by the old "hunch" procedure.

We approach the functional areas of marketing and finance in much the same way. But a reminder: In the first year, all these three functional areas together get only about a quarter of the total time—about the equiva-

lent of a one-semester course in each, if you want to chop it up that way.

In summary, the first year is devoted mainly to foundation building, with a strong introduction to the methods of orderly problem-solving behavior; and to an introduction to the major functional areas in business largely through repetitive problem solving involving integrated use of the analytical tools and methods being learned concurrently.

SECOND-YEAR PROGRAM

The second-year program is built directly on the foundation of the first. About one-half the program is required, the rest elective.

1. *A required full-year course—"advanced business and engineering economics."* In this course we make heavy use of the strong quantitative and engineering backgrounds of the men in the program. This is largely a problem-oriented course, with stress on both learning some of the new analytical approaches and actually using them in handling problems. All students learn to program and use the digital computer on managerial applications. Linear programming, quadratic decision rules, and some advanced managerial economics are customarily included, although the exact course coverage varies from year to year. Further mathematics, for example some set theory, is taught as the students need it to handle the problems they are given. A major problem in the course each year involves going out into industry to handle a "real world" situation.

2. *A required full-year course—"administration and business policy."* This is what the title implies—an integrating, problem-oriented approach to a wide variety of business policy problems, mainly at the upper management level. The first half of the course is devoted to the modern theory of organizations and administration, building especially on the behavioral science stem of the first year. This is followed by intensive use of business policy cases, designed to integrate the various functional fields of business in making company-wide decisions and getting them carried out effectively. It also includes a new complex "business game," developed at Carnegie, which the students play through the entire semester, using the computer. In this, competitive teams must handle the sub-problems within the production, marketing and financial areas of the firm underlying the decisions made in the game, as well as the simple quick decisions ordinarily called for by currently used "business games."

3. *A required half- or full-year course—"ideas and social change."* This course stems from the propositions above concerning the likely future role of business and the businessman in a rapidly changing democratic society. Its goal is to provide perspective on the entire process of social change and of the shifting role of business in that process. Some semesters the course is focused on periods where modern business is intimately involved; other times, entirely different periods of change are analyzed. In all cases, the hope is that the student will begin to understand these processes and to improve his ability to live and lead effectively in tomorrow's world of rapid change.

4. *The rest of the second-year curriculum is elective.* Two comments.

First, there is a restriction that no student can take more than one full year of advanced work in any of the special functional areas—production, marketing, and finance. This much specialization (about a year and a half of course work in a special area) seems to us to be enough to get the man well prepared to do good work when he takes a specific job on leaving the School. Most of his time in graduate school can be better spent building more fundamental tools than in accumulating more particularized knowledge, which I suggest is the main result when more time than this is spent in any one of the functional areas.

Second, in the elective courses available, we are placing stress on what we hope will be fundamental tools—analysis of small group behavior, advanced statistical analysis, modern mathematics, managerial economics, modern data processing, and so on.

At the end of the second year, our hope is that the graduate has a thorough foundation for long range advancement in management, and also a sound foundation to take on a job and do it well promptly on entering industry. *Most important, we hope he has the tools and the frame of mind to learn for himself as the world changes and as he faces different problems from field to field and from firm to firm.*

RELATIONSHIP OF I.A. TO I.E.

What is the relation of industrial administration, so conceived, to Industrial Engineering?

First, Industrial Engineering is frequently focused on a particular functional area of business (the one we call production), while industrial administration, at least as we conceive it, is essentially training for general management combined with training for engineering or science. This means that industrial administration, in our conception, is essentially a graduate program which presumes that the man already has a sound foundation in engineering-science. Parenthetically, we find that students from good Industrial Engineering undergraduate programs are well ahead of the game in the production area, and thus have more time free to push ahead either at a more advanced level in production or in other areas. But they are not usually much farther along than other strong engineering and science students in the other foundation areas.

This difference in breadth of objective and of background is the major difference between I.E and I.A. as we see it. I should suppose the difference would stand out more strongly in comparing our graduate I.A. program with a graduate program in I.E., where there tends to be increasing depth in one special area of production. We believe—though of course we may be wrong—that the foundation a man gets in the I.A. program is about optimal for his going into the various jobs in industry that point toward management, in contrast to technician-type jobs. If a man wants to have a career in, say, operations research, we advise him to go on to the Ph.D. program, where he can push more deeply into the technical aspects of operations research in application to industrial problems.

How do we make use of the special abilities of men from mathematics, science, and engineering? In much the same way as a strong program in Industrial Engineering might do:

1. Throughout, we capitalize on the strong aptitude of the men in quantitative method and their ability in abstract thinking. In the quantitative methods area, we put major stress on modern statistical analysis, especially statistical decision theory.

2. We use their mathematics, and build in some further training in mathematics that would be completely out of the question for non-engineering-science-oriented people—some modern algebra, matrices, advanced calculus—and stress the *use* of these mathmatical concepts in managerial analysis.

3. All students learn to use our digital computer, and we expect them to actually use it, including programming it independently, on come project.

4. In the production and managerial economics areas especially, we push the men faster and further than would be feasible in a business school graduate program.

5. All students are thoroughly exposed to the modern techniques that are often called "operations research"—mathematical programming, game theory, queueing theory, and so on, especially in the required second-year course in "Advanced Business and Engineering Economics." There is a chance for those who want to go on further to do so.

6. We make increasing use of "business games" as teaching devices, especially in the business policy area but also in the functional areas of business. For example, students in the advanced production courses have developed a complete business game of their own, which has forced them to clarify and quantify all the major inter-relationships in the decision-making process in the production area.

The differences between industrial administration and Industrial Engineering may be substantial. But they surely shade into one another, and they have much in common.

CONCLUSIONS

Does the development of industrial administration programs at the graduate level, for engineering graduates, have useful implications for undergraduate teaching? Though I do so with humility, since I am not an engineer, I suggest that much of what I have argued above is applicable to undergraduate teaching in Industrial Engineering or in a special program designed to combine training for management and engineering. Increasingly, Industrial Engineers will need to understand the total management problem to do a good job, as they move from narrower tasks like time and motion study and plant layout to broader tasks such as decision rules for entire production processes. Modern research has demonstrated conclusively that optimum inventory control and production scheduling policies can only be arrived at with full understanding of demand and marketing conditions. Much can be accomplished by sub-optimizing, but eventually managerial decisions must take into account the inter-relations among the many functions and activities of the business. As this occurs, the case for broader training for Industrial Engineers, encompassing an integrated approach to management education something like the one above, will become increasingly relevant and important.

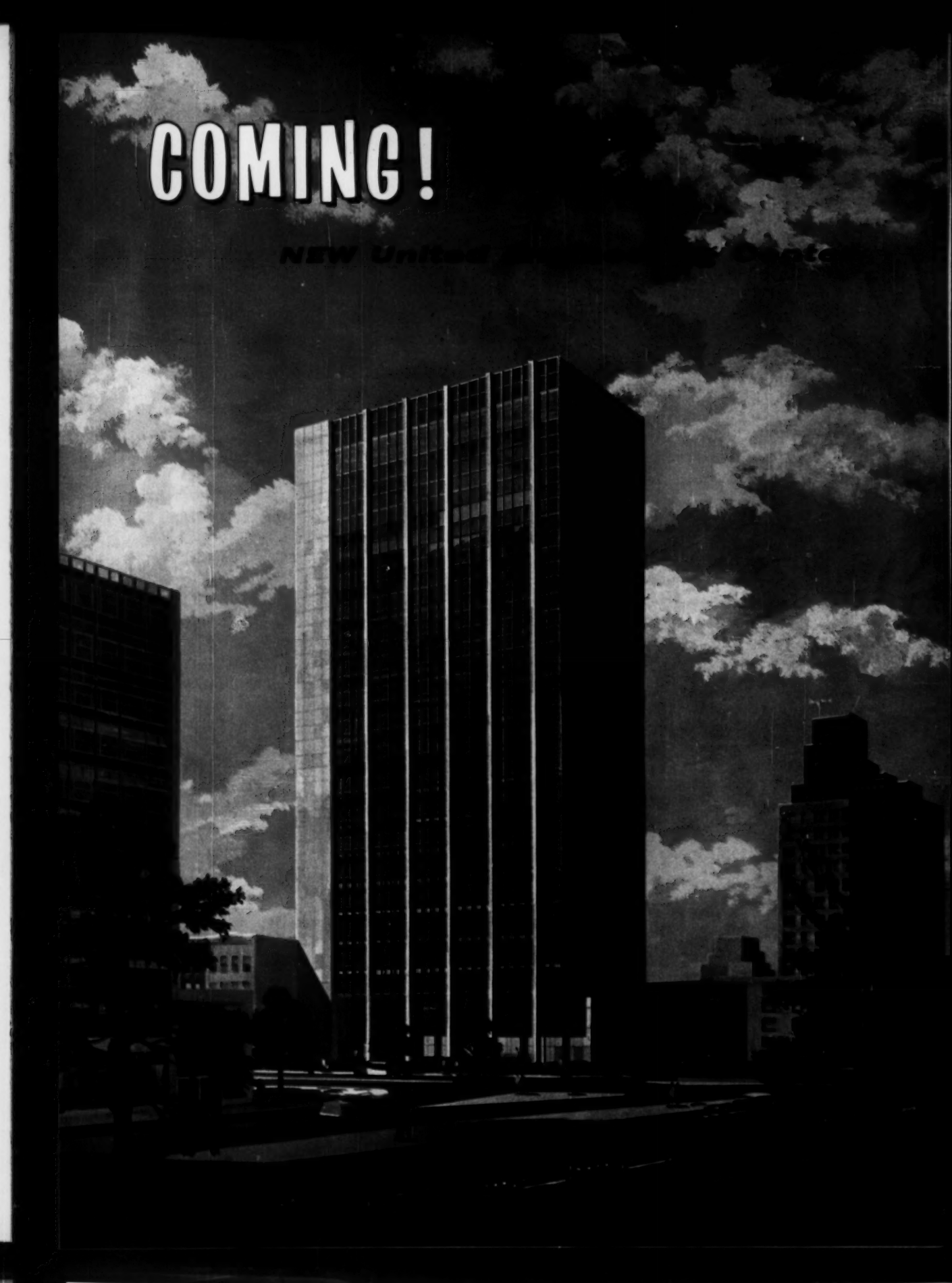
At the undergraduate level it is clear that the pace would have to be much slower than I have implied above, and that more stress would have to be placed on helping the student to learn and apply the analytical tools he uses. Clearly, the less mature man, even though he is of high ability, has a harder job using abstractions and seeing how they can be utilized in handling real world problems.

But two other criticisms must be faced, if one takes seriously the kind of teaching implied above for undergraduates.

First, is the typical undergraduate high enough in ability to benefit from such general, problem-solving education? Even if we recognize that the typical undergraduate is unlikely ever to be president of General Motors or of anything else, the rate of obsolescence of particularized knowledge and particularized training is so great that the more fundamental type of training still seems clearly better for him—even though he gets less out of it than would the more advanced, higher quality student. Why should we fill his head with knowledge that will be largely out of date in a few years, and of which, from all the studies we have, he will remember very little indeed in a few years anyhow? Worse, if he does remember it, the answers he has memorized today are likely to be wrong for the different problems of tomorrow, whether they be answers on how to schedule production, how to organize an accounting department, or how to set market quotas. After scaling down final performance aspirations drastically from the graduate level, my own conclusion is that if we cannot count on the average student's getting more out of a reasonably fundamental program than out of a detailed descriptive program, we should reexamine our entire concept of university education in the scheme of things.

Second, the related criticism that a typical undergraduate will probably be a specialist all his life and ought to be trained thoroughly in some specialty so at least he can do that well. It certainly is true that many of our undergraduates will not even achieve middle management positions, although I am doubtful that we can always pick out which ones will move up and which ones will not. But assume that a man probably will remain a specialized person. First, the evidence is clear that he is likely to end up being a specialist in a different area than the one he picked for specialization in college. This casts doubt upon highly specialized training.

More fundamental is the main point made above that highly-specialized training is not the most useful training even for the specialist. To check this point, go back and read the Industrial Engineering textbooks of twenty-five years ago, and see how much that is there you would want a good Industrial Engineer to use as his main set of tools today. At that level of detail, it may well be that today's best Industrial Engineering practice will do as much harm as good if it is used exactly twenty-five years from today. In conclusion, I suggest that a careful look backward and ahead provides an overwhelming testimonial to fundamental and generalized, as contrasted to highly specialized, college training in Industrial Engineering, and in industrial administration.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COMING! And indeed it is coming — the new United Engineering Center, the beautiful building as shown, in color, on the reverse side.

Commencement of construction in early fall, 1959 . . . Completion of construction by March, 1961 . . . Ready for occupancy by July, 1961 . . . these are the target dates for the new building.

The New United Engineering Center will rise and stand as a monument to a proud and noble profession. Just as its near neighbor, the United Nations on United Nations Plaza in New York City, stands as a symbol of world co-operation, the new United Engineering Center will stand as a symbol of engineering unity and co-operation in the United States. It will be the greatest center for engineering interests in the world. It will be a structure in which every engineer will have justifiable pride.

There is no question that the building will be built. But the drive for funds cannot be allowed to slow down. This message reaches you at a time when we have just passed the three-quarter mark in our fund campaign. The home stretch — and victory in this united drive — lie in the weeks ahead.

Now is the time for all campaign workers to make sure that all members of each section have at least been contacted. It is the time for all sections of all societies to strive for 100 per cent completion of their quotas. It is the time for those sections which already have reached their money goals to keep trying for 100 per cent membership contributions.

And it is also the time for those engineers who already have contributed to ask themselves: "Have I done my part? Have I given to the best of my ability?"

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American Society of Civil Engineers
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Engineers Joint Council
United Engineering Trustees, Inc.
Welding Research Council

Reader Comments

THE INDEPENDENCE OF PACE RATING VERSUS WEIGHT HANDLED, by C. B. Gambrell, Jr., *Journal of Industrial Engineering*, July-August, 1959.

WAS GAMBRELL'S ROCKET FUELED WITH EXOTIC STATISTICS?

Gambrell claimed to have established the following conclusion, "One should *reject* the . . . hypothesis that Ratings Made by Skilled, Thoroughly Trained, and Practicing Time Study Analysts Using Pace Ratings Are Not Influenced by Job Difficulty." He goes on to claim that he has established that *Weight* (*per se*) and *Size* (*per se*) have a significant effect upon ratings made in this manner. While disclaiming any attempt to relate his so-called "statistical significance" to "practical significance" (see his conclusion 6) he does indicate under his *results;* "Therefore, this raises a question concerning the use of weight as a separate adjustment category. To do so assumes that the analysts are not already correcting, at least in part, for weight in their pace ratings."

Such definitive conclusions as are offered, call for a careful study of the data concerned, in order to determine the validity of such statements, particularly when made without qualification or limitation.

As will be shown, the data do not really support his conclusions but indicate primarily gross errors in statistical inference, dubious adventures in curve fitting, and an apparent failure to recognize the data's more obvious import.

Gambrell's experimental design was factorial in that several variables were altered simultaneously. The basic method of statistical analysis chosen was appropriate for these data.

Some notes concerning such an "analysis of variance" are in order. This type of statistical treatment was originally devised by agricultural experimenters who had to determine the effect of various varieties, soil treatments and the like, simultaneously and could not either assume independence of the variables or maintain conditions constant while one variable was experimentally altered.

For instance a group of fields might each be divided into subsections and subsections in each field planted to various varieties, and different soil treatments and fertilizers given to various plots. The analysis of variance was devised to determine in which group of plots apparent non-chance cause differences occurred and identify the apparent cause. For instance, four soil treatments A, B, C, and D may have been used. The analysis of variance for soil treatment, if significant results are obtained, will indicate a significant amount of variance from "soil treatment." This does not mean A, B, C, and D are all different—only that at least one treatment appears to be different more than chance variation would lead us to expect. For instance, soil treatment (A) may have consisted of plowing in pure white sand; (B), pure brown sand; (C), pure gravel and (D), 10-10-10 commercial fertilizer. Because the analysis of variance indicates a significant difference from "soil treatment," this would not permit one to conclude that all treatments had an effect and represented a continuum of some "treatment" variable.

I have gone in detail in the analogy so as to have a fresh view for examining Gambrell's data. The variable of weight, for plant A, shown as significant at the 1% level, does not mean that the continuum of weight (he used boxes of 5, 10, 20 and 40 lbs.) all affected the ratings. If one weight had an apparent non-chance cause effect, this result would have ensued. It is still necessary to examine the various weights used and determine (among other things):

a. Which weight or weights affected the rating.
b. The magnitude of the effect.

I have taken the raw data from his thesis for Plants A and B and averaged the ratings by combining the ratings given all four sizes of boxes and all four paces, for each weight. The following means result:

Weight	Gambrell's symbol	Plant A	Plant B
5 lbs.	W_1	68.1	72.3
10 lbs.	W_2	71.6	75.2
20 lbs.	W_3	69.6	74.1
40 lbs.	W_4	67.0	73.0

In his "results" under "weight" Gambrell goes on to point out that *weight* (he uses this term *per se*) had a significant effect at Plant A but not at B and continues; "the weights which affected the analysts most, thus causing the significant difference, were five pounds versus ten pounds and ten pounds versus forty pounds." This is a most misleading way of saying that the ratings given the ten pound weight were significantly different from those assigned the five pound and the forty pound weights but the *ratings assigned the five pound, twenty pound and forty pound weights were not significantly different.* He is compounding the error when in his results section, he talks about a curve (fitted to four points, three of which are not statistically significantly different) with "the apex of the function at the ten pound weight."

Gambrell is apparently unaware that statistical significance does not prove causality. Like the fertilization treatments referred to earlier, one significant point in what is *presumed* a continuum does not establish the validity of the assumption that the imposed "continuum" is *per se,* the variable. Indeed, in the case of weight, one would suppose that if ten pounds created an error, twenty pounds and forty pounds would create more error. An examination of the data reveals this is not so. The continuum is not what Gambrell claims and we must seek more appropriate conclusions.

Three conclusions are possible from Gambrell's data, none of which resemble the one he offers. These conclusions are:

1. Weights of 10 pounds affect the pace ratings significantly as compared with weights of 5 pounds, 20 pounds, and 40 pounds, *the last three weights not having any significantly differential effect upon ratings.*
2. Some peculiarity existed in the handling of the ten pound weights as filmed.
3. Some unknown but non-chance cause affected the ratings of scenes including the ten pound weight.

Conclusion 1 should disturb any researcher in that it suggests a unique relationship between one weight and pace ratings for which no reasonable, logical explanation seems available. On the other hand, Gambrell states that the scenes of each weight were filmed in sequence; all W_2 (10 pound) scenes were filmed at one time. That they contain some unique characteristic, (not related to weight) as suggested in Conclusion 2 is far from being ruled out. If the worker varied his motion path or distance some small amount between the filming of W_2 and W_1 this would cause this result. It must be borne in mind that the objective rater accepts method (in all its ramifications) as established for rating and even if the time for each W_2 performance was the same as equivalent

scenes of W_1, W_2, and W_4, but the path of motion was slightly longer, the rating would be higher. Other differences imposed in filming could affect rating of W_3 scenes without disturbing the tenability of the hypothesis Gambrell was testing. It is worth noting that even though weight did not include a significant difference at Plant B, the average rating assigned W_2 was higher than for W_1, W_3 and W_4. Indeed, if W_3 was eliminated at Plant B (and this was not in Gambrell's quoted significances at Plant A), it is not unlikely that W_2 might again show significance. At any rate, because of a statistically significant difference, attributable to *one weight* at *one* of two plants, Gambrell concludes that *Weight per se* is a variable in rating. This is a wild order of statistical inference. Conclusions 2 and 3 are certainly more tenable, more in keeping with the data although, unfortunately, less dramatic.

The earlier remarks of Gambrell concerning the correctness of an adjustment for weight are also most interesting when examined in the light of his actual data. The average ratings assigned W_3 in Plant A were 2% more than those assigned W_2 yet this difference was not statistically significant. Hence, we may say that the ratings assigned W_3 (whatever caused the difference) *were less than 2% more* than chance alone would cause us to expect. The actual difficulty adjustments commonly used for the weights involved are at least (compared to moving zero weight) for 5 lbs, 4%; 10 lbs, 11%; 20 lbs, 21% and 40 lbs, 37%. (See *Journal of Industrial Engineering*, July-August, 1957, page 237, which contains more recent data than Gambrell quoted.) To question these and to claim time study men may be correcting in part because one weight at one plant received a rating (for some unexplained reason) *of less than 2% more* than we would expect, is indeed inference of a peculiar order and highly gratuitous.

But we have not finished. Gambrell's inferences concerning size are even more tenuous. The following are the mean ratings given each size of box at each plant, combining the various weights and paces for each size:

Size	Gambrell's symbol	Plant A	Plant B
8-⅞″ × 8-⅞″ × 8-½″	S_1	68.4	72.8
9-¼″ × 19″ × 6″	S_2	68.6	72.3
10″ × 12″ × 13-¼″	S_3	70.3	76.0
11-⅜″ × 18″ × 12-⅞″	S_4	69.1	73.5

Gambrell says, (in his results) "The presentation of different size containers did not influence the ratings of the analysts at Plant A but did at Plant B." Note the *assumption* of a continuum! He further fumbles a most reasonable answer when he notes, "box number three was the only one of the four boxes which was higher than it was long or wide. The height feature of this particular box may account for the adverse influence which its size had on the pace ratings."

Neglecting the weakness of conclusions founded on data significant at the 5% level (we should get such data 1 out of 20 times by chance and we do have 16 weight and size means) let us examine what conclusions are actually tenable with these data:

1. Boxes of size S_3 significantly affect ratings as compared to boxes of size S_1, S_2 and S_4.
2. The height of box S_3 caused a slightly longer motion in clearing the side of the box and reaching the grasping location. This longer motion, performed in the same time as the shorter motions for boxes S_1 and S_2, was detected by the analysts at Plant B and apparently assigned a higher rating —*as it should have*. The same effect is suggested from the data from Plant A but the error term is too large to permit this to be definitely ascertained.
3. Some unknown, non-chance cause affected the data from size S_3.

Even conclusion 1, which is as far as Gambrell should have gone, had he insisted on going in the same direction as his definitive conclusion, but stopped at a more appropriate point, is hardly tenable nor is it proof that size was a continuum. Refer to the dimensions if you want to appreciate this, particularly since Gambrell in his "results" attributes this to "the cubic effect of the relationship of sizes presented" and in his complete thesis actually fits a third order equation to the ratings versus the cubage of four boxes, even though three of the four points are not statistically significantly different. Of this relationship, Gambrell says: "Analysis of this relationship revealed that it is probably a unique one for the particular size boxes used and extrapolation of the function would be risky." Even this statement should be rephrased to read, "Is a unique one for the specific values of the data (disregarding the reliability of individual values) and giving credence to the apparent relationship would be erroneous. A third order equation can be fitted to almost any four points and presumes a remarkable theoretical explanation."

Certainly conclusion 2 just given, is the most tenable and is in direct opposition to Gambrell's conclusions. Even conclusion 3 of the preceding list is not ruled out.

At this point it should be obvious that continuing the discussion into the supposed interactions is hardly profitable.

To summarize my conclusions:

1. Gambrell's conclusions are not supported by his data. He has misinterpreted his analyses of variance to mean that each condition of the variables affected the pace rating while in actual fact one condition exhibited some unique values with far simpler although less dramatic explanations than those offered. His supposed continuums are not established as such unless one accepts most peculiar hypothesis involving second and third order equations, fitted to points not statistically different. Further, his supposed interactions and even the meaning given the apparent unique differences are highly dubious.

2. The magnitude of the differences accompanying the unique values (*even if they were real*) are far less than the adjustment made for the variable using the usual difficulty adjustments. Gambrell's questioning of the correctness of using or not using a difficulty correction is without basis and purely gratuitous.

3. The data actually lend more support to the hypothesis that objective raters assign a rating essentially independent of size or weight and the basic concept of objective rating is highly tenable, in direct opposition to the conclusions he imposed upon his data. Indeed, it appears as though the raters do this with sufficient precision such as to detect errors unknowingly introduced into the experimental situation.

4. While claiming to be directed at improving our understanding of a rating procedure, Gambrell's paper is an eloquent illustration of how far into space one can go with mean errors in rating of 2 and 3 percent using exotic methods of inference.—*M. E. Mundel, M. E. Mundel & Associates.*

AUTHOR'S COMMENTS

I appreciate Dr. Mundel's interest in my article and especially the time he must have spent in preparing his comments. It is interesting to note that he and I are in agreement regarding many facets of my research. This is evidenced by the fact that he chose to disagree only with those points which tend to disprove his theories. It is, of course, quite natural to remain silent when "exotic statistics" support ones position and conversely to become aroused when "exotic statistics" do not compliment ones theories. It is interesting to observe that he is quite willing to accept on the one hand and to demolish on the other hand features which come from the same experimental design. It is, however, reassuring to know that he agrees with me, even if only in part.

I should like to point out again as I did in paragraph 6 of the

conclusions section that it was beyond the scope of my study to evaluate "statistical significance" versus "practical significance." Inferences drawn as a result of Tables 1 and 2 were purely of a statistical nature because statistical significance can be universally defined, whereas it is impossible to obtain agreement as to what practical significance really is. I might say further that the experimental design was not only sensitive enough to detect a statistical significance of .01, in most cases it did better. Further analysis of the results, show that in every case where a statistical significance of .01 was detected, the actual significance indicates that the probability was less than .0005.

It appears to me that the results of this research provide a counter example to Mundel's theorem that *pace ratings are not influenced by job difficulty*. It is well known by those persons who have a knowledge of basic engineering mathematics that one counter example is sufficient to disprove a theorem. It is, of course, possible to modify a theorem, as apparently Dr. Mundel does by his comments when he states that a difference of 2% or 3% is insignificant. However, I was not aware of his modified theorem in precise detail. Unaware that 2% or 3% is insignificant, I, in my research, did not know how high this percent could or should go. Therefore, an upper bound could not be provided for my statistical analysis. I used the traditional statistical hypothesis that the average ratings are all the same. This is the hypothesis that was rejected.

The question which needs to be answered is how great is this job difficulty contamination of the pace rating. Actually it could be large or small. The adjustment for an arm lift of fifty pounds equals nearly twice the amount (48%) of adjustment recommended for the most extreme conditions of all other five secondary adjustment categories combined. It is obvious then that the most important adjustment category is *weight*. I am aware of the changed values for weight which Mundel recommends, however, these new adjustment values were not in use at Plant A at the time of the study. An error in applying these values, new or old, could be serious. The error I have in mind here is not an error in selecting some value from a prepared table and applying it. The error which this research investigated arises from the assumption that the application of that chosen tabular value completely corrects for the situation.

We all know that it is impossible to regiment the mind of man and especially the mind of a methods and standards analyst. This research shows that analysts cannot be completely objective in their rating of pace and that they do tend to be influenced by job difficulty. On the other hand this research does not point out whether this difference is of practical importance. The determination of this relationship would be an excellent topic for further research.

Although there are other points made by Dr. Mundel, these can be shown to be basically a difference in hypotheses being tested. These differences in turn point out the need for further research in this important area of Industrial Engineering.—*C. B. Gambrell, Assistant Professor, Department of Industrial Engineering, Purdue University.*

ORDER SIZES FOR JOB LOT MANUFACTURING, by R. W. Llewellyn, *Journal of Industrial Engineering*, May-June, 1959.

Following are some corrigenda to Professor Llewellyn's article.

Page 176 "The standard deviation for the binomial distribution is:

$$\sigma = \frac{\bar{p}(1 - \bar{p})}{n}"$$

This should read: "The standard deviation for the fraction defective is:

$$\sigma_p = \sqrt{\frac{\bar{p}(1 - \bar{p})}{n}}.$$

. . . . . .

$$"\sigma = \frac{p(1 - p)}{n} = \frac{(.05)(.95)}{900} = .00005278 = .00737$$

$$p' = \bar{p} + 1.645$$

and $$p' = \bar{p} + 1.645(.0073) = .0620."$$

This should read as follows:

$$"\sigma_p = \sqrt{\frac{\bar{p}(1 - \bar{p})}{n}} = \sqrt{\frac{(.05)(.95)}{900}}$$

$$= \sqrt{.00005278} = .00727$$

$$p' = \bar{p} + 1.645\,\sigma_p$$

and $$p' = .5 + 1.645(.0073) = .0620."$$

Page 177:

$$"\sigma = \frac{.0475}{960} = .00703."$$

This should read:

$$"\sigma_p = \sqrt{\frac{.0475}{960}} = .00703."$$

"Using the same data as before:

$\sigma = .00727$ (in the first approximation)

$p' = \bar{p} - 1.6456 = .05 - 1.645(.0073) = .038."$

This should read:

"Using the same data as before:

$\sigma_p = .00727$ (in the first approximation)

$p' = \bar{p} - 1.645\,\sigma_p = .05 - 1.645(.0073) = .038."$

Although Grant's text is referenced, the notation differs from Grant's (and Duncan's) usage. If the standard deviation (of the binomial distribution = $\sqrt{np'(1-p')}$ is used, the notation should be σ—The standard deviation of the fraction defective should be notated σ_p. Grant uses p' to designate the true population fraction defective, with $\bar{p}$ as the best estimate of p'. In this article, however, p' is used to denote the value $\bar{p}+1.645\,\sigma_p$. This practice is confusing.—*B. Lewis Brinson, Jr., Statistician, Robins Air Force Base, Warner Robins, Georgia.*

AUTHOR'S COMMENTS

The comments of the alert Mr. Brinson on my article "Order Sizes for Job Lot Manufacturing" are correct as they stand. The reference to the standard deviation as that of the binomial distribution rather than that of the fraction defective is not good statistical practice and should be regarded as a mistake on my part. The 1.6456 that appeared instead of 1.645σ was a typing error which I did not catch in the manuscript. The others were errors of omission and are correctly inked in on my copy of the manuscript. Since I did not regard this as a quality control article, I did not attempt to follow Grant's notation and was using only his Table G.

My thanks to Mr. Brinson for noting these errors and I hope future articles from me will be free of this type of gremlin.—*R. W. Llewellyn, Associate Professor of Industrial Engineering, North Carolina State College.*

(EDITOR'S NOTE: Sorry, we contributed to the confusion.)

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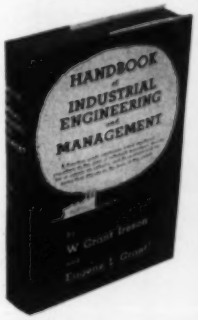

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President's Message

FRANK J. JOHNSON
President, American Institute of Industrial Engineers, Inc.

1959-60

Our Institute and Research

IN searching for timely subjects that could be used in this year's series of "Messages," I realize that there is very definitely a "need to know" among the rank and file members of AIIE concerning activities of our major committees. This is particularly true because of the almost explosive growth of our organization. No other engineering group increases itself by one-fourth each year and continues this growth for six consecutive years as we have done.

The first message in this series will be devoted to the responsibilities and activities of our Research Committee under the able guidance of Professor Andrew Schultz, Jr. of Cornell University, who serves our Institute as National Director for Research. I am indebted to Andy for his own bit of research concerning the many facets of his committee in order that I can make this report to you.

The Research Committee as it now exists is the result of a proposal made by the Director of Research to the Board of Trustees in 1955. Although this was only four years ago, nearly two-thirds of our present members had not yet joined AIIE. This is just another comment on our growth and perhaps another reason for the necessity of writing this series. This proposal was designed to fit into the existing organization of the Institute with a minimum of conflict, to replace the then existent research organization with a minimum of disruption and be adaptable to expansion into the divisional type of organization into which ASME ultimately developed, into which ASQC is moving, and into which most large technical groups seem to evolve.

There are ten specialized research committees, all of which are activated, and five functional committees, of which three have so far been activated. The Research Support Committee and the Fellowship Encouragement Committee have not yet been activated, but the other functional committees are operating. The Research Council is not yet organized. A brief description of the functions of these committees is outlined below:

Specialized Research Committees:

R-1 *Work Measurement*—To include time study, work sampling, standard time incentive plans, standard data plans, etc.

R-2 *Methods*—To include work simplification, motion study, aspects of tool engineering, automation, work-place design, etc.

R-3 *Plant Engineering and Design*—To include layout, handling, equipment selection, maintenance, plant location, buildings, etc.

R-4 *Human Relations*—To include job evaluation, merit rating, personnel management, industrial relations, safety engineering, non-standard time incentive plans, etc.

R-5 *Engineering Economics*—To include equipment policy, engineering economy, investment, replacement, etc.

R-6 *Organization Planning*—To include organization study, planing, design, measures and relationships.

R-7 *Quality Control and Industrial Statistics*—To include inspection, gaging, statistical quality control, standards, and specifications.

R-8 *Production Control*—To include production forecasting and planning, materials and inventory control, production routing, scheduling, dispatching and follow-up, etc.

R-9 *Data Processing Systems Design*—To include communication procedures, information flow, record keeping, cost control, reporting etc.

R-10 *Operations Research and Systems Design*—To include areas not covered in other committees which involve new research applicable to Industrial Engineering and over-all systems design.

Functional Research Committees:

F-1 *Research Prize Committee*—To provide positive encouragement for research in the form of prizes.

F-2 *Fellowship Encouragement Committee*—To encourage the granting of graduate fellowships in the area of Industrial Engineering, to develop criteria and method of selection, and to select recipients of fellowships when the Institute provides for such.

F-3 *Research Information Committee*—To provide to the Research Publication Committee each year a classified list of titles and abstracts of graduate theses in the field of Industrial Enginering, to maintain satisfactory liaison with research agencies of other societies, and to provide, where it seems feasible and desirable, historical reviews of research titles and abstracts.

F-4 *Research Support Committee*—To develop industry, foundation, and government agency interest and support of research in the area of Industrial Engineering.

F-5 *Research Publication Committee*—To provide for the publication of research information, papers, monographs, or theses which cannot be published in the *Journal of Industrial Engineering* but which should be available, because of their importance, to members of the profession.

The real objectives of the research organization should change as time passes. The initial objectives, which still continue, are fundamentally educational and secondarily facilitative and communicative in nature. They are to provide within the formal structure of the AIIE a focus for questions related to research, a mechanism for the interchange of information about research, a means for defining for the organization a qualitatively high standard with regard to questions concerning Industrial Engineering research, and a mechanism to bring before the membership and other professional groups a realization of the scope, content, needs, and performance of Industrial Engineering research. The specialized committees, by meetings, discussions, symposia, refereeing of papers, and presentation of technical sessions at AIIE meetings, have been providing these functions. The functional research committees, through the collection and publication of abstracts, through the award of prizes, and ultimately by publication of monographs and supporting research by encouragement of graduate fellowships or foundation or governmental support, make an equally important across-the-board contribution. It is noteworthy that it is not the function of the research organization to 1. compile bibliographies, 2. maintain a glossary, 3. make surveys to find out how industry is doing it, or 4. actually do research. Naturally, the individuals on the research committees have an interest in their areas of specialty, have full-time jobs of some sort or other, and may in fact be doing research themselves. But research is not accomplished by committees and it is not done in odd moments. One man-year of research costs from $20,000 to $30,000, depending upon facilities used. The problems of Industrial Engineering are not simple. They are rather complex and they demand considerable effort and competence. To the extent that the research organization is able to maintain its reputation and competence by attracting appropriate professionals to its committees, it will be able to achieve its objectives.

Some specific accomplishments are worth noting. Five of the research committees have held symposia. Some of these have involved a relatively small number of leading specialists in the field such as the Methods and Work Measurement Symposia held at the Syracuse Regional Conference in October, 1958. Others, involving a larger invited list of specialists, were held on a national scale and resulted in publication of proceedings. The Organization Planning Seminar in New York and the two Simulation Seminars in New York and Chicago are representative of this type. The Engineering Economy Symposium on New Applications of Economic Evaluation in Industry held in cooperation with the ASEE was a successful illustration of a larger scale meeting. All of these served the purposes of the research committees to appraise problem areas for purposes of pure research and of applied science, and to develop methods of application. In addition they were of value in encouraging research in Industrial Engineering and on Industrial Engineering problems. They further served to bring before the eyes of other cooperating organizations the interest, competence, and scope of Industrial Engineering professionals in the problems discussed. Our field is being defined in this way as well as in others, and the future development of the art cannot help but benefit and be influenced by these rather fundamental actions.

Another activity of the various committees has been to hold meetings at which the various problems of the specialized area are discussed. Through the activities of the committee membership in other associations and through their writing and speaking, the course of developments in the area is affected.

The roster of the committee members of the research organization demonstrates the influence of the group. There are few such members who are not actively participating in many technical meetings throughout the country, and they represent the AIIE and its position on research competently and ably in these activities.

Finally, such specialized committees as Production Control and Work Measurement provide speakers, chairmen, and panelists for higher level technical sessions at AIIE meetings. The series at the recent national con-

ference in Atlanta was well received and appreciated by those who found their way to the top floor of the hotel.

The functional committees also are providing a very essential service to the organization. The Research Information Committee collects material from all over the world, classifies it, and publishes abstracts of research taking place in Industrial Engineering. There is no means other than this where researchers in the field can find out what others have done and thus avoid undersirable duplication or repetition of effort.

The Research Prize Committee has the important function of generating and screening nominations to select outstanding research accomplishments in the field. Through such recognition by suitable awards it is hoped to encourage good research, to increase research efforts, and to point out to others the quality of performance in the field.

A question that should be discussed is what the local senior and student chapters of the AIIE can do to aid this effort. There are a number of activities in which the research organization needs aid. One is the collection of abstracts of research work in the area of the chapter. There are many educational institutions and industrial organizations which have been doing research but which have not yet prepared abstracts on the forms provided by the Research Information Committee. Local organizations can follow up to see that this is done. Secondly, the nomination of any outstanding local research accomplishment for award should also be a service the local group can provide. A most effective aid would be the encouragement of local firms to provide graduate fellowships in Industrial Engineering at educational institutions, the encouragement of such firms which already provide college graduate fellowship support to write their grants so as to include Industrial Engineering, and the organization of a local basis of awards or recognition of good work done by chapter members or local students in application of new techniques or development of new applications or techniques. A metropolitan chapter could very well make an award each year for high quality theses written by graduate students in Industrial Engineering in local educational institutions.

Obviously, the problems of development of an appreciation of good research, of appraising needs for further work, of increasing the prestige and status of Industrial Engineering, and of encouraging more research is complex. It is felt that a very creditable start has been made, but a broader foundation and continuing growth are essential if our Institute is to properly mature so that it may assume the professional dignity which it deserves.

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CONFERENCE AND CONVENTION

The Eleventh Annual Conference and Convention of AIIE will be held:

DALLAS, TEXAS

Sheraton-Dallas Hotel

MAY 12, 13 AND 14, 1960

PLAN NOW TO ATTEND

Institute Interests

PROFESSIONAL RELATIONS ACTIVITIES

Engineering Unity at the Chapter Level

It is no mere coincidence that each of the last five issues of the *Journal* have carried material pertinent to the subject of improved coordination within the engineering profession. This past year has been one of eventful action even for those who believe that we are moving all too slowly in the direction of unified activity. It would be wonderful to be able to report that all engineers and all engineering organizations agree to all the aspects of unification. This may never be. However, the accomplishments of the past year, as reported in the *Journal,* have been pointed in the direction of bringing closer to reality the aspirations of those seeking unity among engineers.

Representation of the AIIE in Engineers Joint Council is assurance to all of us in the Industrial Engineering profession that we will be directly involved in any study or action at developing a program that will further the objectives of the engineering profession as a whole and promote the most effective utilization of engineers in maintaining the national health, safety and interest. In three years the number of delegates from our society has grown from one man, Dr. Rathe, to thirty—many of whom are from the top ranks of industrial and academic circles. All these men have had to make personal sacrifices in order to devote time and effort in promoting the interests of the engineering profession.

However, while this activity has been going on at the national level, a survey made this past year of all of our local chapters indicates a very strong pattern of coordination that a politician might describe as being of the "grass-roots" variety: The lowest echelon of the profession—the engineer—the man that the societies represent—is always working with his fellow engineers hand-in-hand in many different ways. He has in many instances accomplished that which the societies are still seeking.

Last Fall, acting on the theory that more de-facto unity existed in individual communities than was generally realized, Jim Richardson was requested by the Professional Relations Committee to contact the individual chapters of the AIIE to determine the extent of their relations with local engineering organizations.

Answers to three questions were specifically sought:

1. Whether or not any form of local Engineering Organization existed which would tend to promote Engineering Unity.

2. In what manner did AIIE cooperate with such a body, i.e., through its individual members who also belonged to the local organizations or by virtue of AIIE Chapter Membership.

3. AIIE Chapters were asked to elaborate on the scope of activities of any local engineering organization and the scope of their participation.

Fifty-five (out of ninety-four) chapters replied in detail. Forty-six of the fifty-five reporting chapters indicate the existence of some form of local engineering organization open to engineering societies. Nearly every chapter is participating in the activities of its local body of engineers.

As might be expected, the nature, size and strength of the local organizations vary considerably. It would be necessary for an interested party to read the chapter replies in detail to appreciate the extent of local engineering unity. Sample quotes include:

"Among societies with whom we cooperate at the local Chapter level are The Institute of Management Sciences, American Society of Quality Control, Institute of Radio Engineers at present. Past efforts also included American Society of Mechanical Engineers, American Material Handling Society, New York Society of Professional Engineers, Operations Research Society of America, and the Society for Advancement of Management.

We are currently negotiating with the American Institute of Electrical Engineers and the American Society of Mechanical Engineers in an atempt to join them in their fine program of courses on public speaking, report writing, etc., as well as P. E. preparation."

"Architect's and Engineer's Institute—The A&E Institute owns a good sized building in the downtown area of Atlanta. The governing board of the institute is composed of an appointed member from each of the local architectural and engineering societies. The facility provides meeting and office space for each society, (meals are served) and is financed through permanent exhibits of building and industrial products. An engineering reference library is also maintained."

"The Cleveland Technical Societies Council is composed of fifty-one member societies among which are the AIIE Chapter and the Cleveland Engineering Society. The objectives of the Council are to bring together the members of the technical, scientific, architectural and engineering societies in the Northern Ohio area for cooperative effort in increasing the scope and availability of the services of the societies to individual members, and to promote intersociety activities and good will.

Last year the Cleveland Engineering Society consisting of about 2,000 members moved into a new $1,500,000 home. The AIIE now hold all meetings in this building. We also have two delegates to the CTSC."

"Technical and Scientific Council of Cincinnati composed of twenty-three local sections of national societies—approximately 6,154 individual members.

The Council has a building called Engineering Society Headquarters. The Local Chapter AIIE has almost all meetings in this building."

"Our local AIIE chapter participates, through chapter membership, in the Engineering Council of Birmingham and Jefferson County. The enclosed copy of the roster, constitution, and objectives of the Engineering Council will explain the scope of activities, size, etc. of this organization much better than I can."

"Members of Engineers Joint Council of St. Louis take an active part in their work. We have an advisory Committee and a three man delegation."

"Society of Professional Engineers—several hundred engineers—same general activity as the National organization; Engineers Joint Council—a committee composed of the president and one other representative from each of the individual engineering societies set up to promote items of interest to all engineers, engineering education, and counseling."

"The Puget Sound Engineering Council is composed of twenty-nine member societies of Seattle and Tacoma, including all the senior societies and the Washington Society of Professional Engineers. It is active in legislative and public relation matters."

"The Youngstown Chapter of AIIE has two delegates to the Mahoning Valley Technical Societies Council, Youngstown, Ohio; each delegate is appointed for a period of two years."

"Engineering Societies of New England—approximately 8,000 members—constituent members—twenty-six engineering societies in New England including all branches of Engineering (Also Merrimack Valley Chapter, AIIE)—ESNE very active in securing

passage of mandatory registration of Professional Engineers—effective 12/26/58—recognizes Industrial Engineers for first time in Massachusetts."

"Toledo Technical Council has thirty-one member societies with approximately 3,200 members. Engineering Society of Toledo has approximately 500 members."

These answers were randomly selected and represent a good cross section of unified activity in communities throughout the country. So what? It seems to this reporter that a form of Engineering Unity exists. It might almost be said that more unity exists at the "grass roots" than exists at the national level.

The information gathered in this report might suggest that if any concerted drive for unity were to take place, it would do well to take advantage of the ready-made unity already existing in local communities.

Unity within the engineering profession dates back to 1852 when the American Society of Civil Engineers was founded. The formation of that Society was the answer to a need; our local chapters are participating in programs coordinated to serve a number of engineering societies within a given area who have much in common. This coordination is also an answer to a particular need in that community.

The recognition of the need for coordination at a national level is a matter of time. The single most significant development during the past year has been the unanimous stand by all EJC Directors in favor of an amalgamation of the activities of the EJC and the ECPD. Its realization would bring us a big step closer to the time when one group can speak for all of the engineering profession.

Reported for the Professional Relations Committee
BY O. J. FEORENE

CALENDAR

October 12, 13 and 14: International Systems Meeting to be held at the Royal York Hotel in Toronto, Canada. Write: George K. MacDonell, General Chairman, International Headquarters, 4463 Penobscot Building, Detroit 26, Michigan.

October 23: Conference on the Arbitration of Wage Incentive Grievances to be held in Buffalo, New York. All of the speakers are well-known arbitrators with special knowledge of incentive arbitration. Write: Richard M. Gordon, Western District Director, Extension Division, New York State School of Industrial and Labor Relations, Cornell University, 17 Court Street, Buffalo 2, New York.

November 11, 12 and 13: The Sixteenth National Meeting of the Operations Research Society of America will be held at the Huntington-Sheraton Hotel. Registration can be made at the meeting. Hotel arrangements should be made directly with the hotel. Write: Sidney I. Firstman, Publicity Chairman, The Rand Corporation, 1700 Main Street, Santa Monica, California.

January 25-February 4, 1960: The 1960 Engineering and Management Course, an intensified 10 day short course for engineers and managers (excluding Sunday), Los Angeles campus of the University of California, tuition $400.00. Write: College of Engineering, University of California, Los Angeles 24, California.

PERSONALITIES

ROBERT N. LEHRER

Robert N. Lehrer, Chairman of the Department of Industrial Engineering at the Northwestern University Technological Institute and Editor-in-chief of the *Journal of Industrial Engineering*, was among four American engineers who spent six weeks in Japan this summer under a program designed to increase productivity of Japanese industry.

Prof. Lehrer was primarily concerned with office work simplification and procedures analysis during the instruction courses offered to middle management officials in the Japanese industrial cities of Tokyo and Osaka.

Other members of the group, organized by the Japanese Productivity Center and the International Cooperation Administration (ICA) were M. E. Mundel, Management Consultant of the City of Milwaukee, who was group leader; A. L. Bryant, Director of the Management Engineering Training School at the Rock Island (Ill.) Arsenal; and Calvin Schneider, Chief Industrial Engineer for a Cleveland manufacturing firm.

Upon arrival in Tokyo, the group spent four days in orientation and discussion of the program, which is part of an over-all plan organized by the Japanese Productivity Center that has included visits to this country by Japanese industrialists. Several Japanese were enrolled in courses in the Northwestern Industrial Engineering Department during the winter and spring academic quarters.

Special two-week courses for the middle management group were presented both in Osaka and Tokyo. Mundel conducted the course in work method improvement and work measurement; Bryant specialized in organization planning; Schneider in work planning and control; and Lehrer in office work simplification and procedures analysis.

Seminars with top management were also scheduled. The "middle management" group was composed of individuals more directly concerned with actual operations than with long range planning and policy formation which is the interest of top management.

FLOYD J. TITLER

In a letter mailed to the Board of Trustees, National Directors and Chapter Presidents, our National President, Frank J. Johnson, announced the impending retirement of Floyd J. Titler, Executive Secretary of AIIE. Excerpts from this letter follow.

"For those of you not familiar with the background, the position of full-time Executive Secretary for our Institute was created by the Board of Trustees in the fall of 1957. Floyd Titler, who was the first man to be elected to the newly created post of First Vice President, retired from Republic Steel Corp. in February, 1958, and he consented to becoming our first full-time Executive Secretary for a two-year term. This term expires in February 1960, and Floyd has requested that we allow him to retire at that time.

"It is with mixed emotions that we accept Floyd's decision to step down in February—with regret that we are losing the services of a fine gentleman with a world of experience and an abiding love for our profession and Institute—yet we are happy that he can enjoy some well-earned rest and leisure.

"Due to the impending move of our national headquarters to the United Engineering Center in New York City, it will be necessary to employ a new Executive Secretary in time to assist us with the planning for our move. The Executive Committee is screening possible candidates for this position.

"Effective last July, Floyd Titler became Executive Secretary-Emeritus and he was relieved of the major part of his responsibilities for operating the headquarters office in order that he may have time to work on some very important special assignments relative to our national headquarters organization and move to New York City. He will assist in the training of his replacement when the selection has been made and approval received from the Board of Trustees. Don Trenwith, our Business Administrator, will manage the operations of our national headquarters office during this period.

"I know that all of you join me in wishing Floyd the very best of good health and happiness as he approaches retirement in his 'second career.' Most of us will be doing well if we can retire from one career."

SAN DIEGO CHAPTER WINS GROSECLOSE AWARD

Winners in the Chapter Development contest were announced at the Annual Conference Banquet held in Atlanta, Georgia on May

14, 1959. First place award went to the San Diego Chapter. Larry Becht, chapter president accepted the FRANK F. GROSECLOSE AWARD on behalf of his chapter. This marks the second time the trophy went to the Western Region, Great Salt Lake having won the first award last year.

Listing of other award winning chapters follows:

1st	Runner-up		Dallas-Fort Worth
2nd	"	"	Milwaukee
3rd	"	"	Great Salt Lake
4th	"	"	Charleston-Huntington

Regional winners were:

Northeast—Central Connecticut
Southeast—Nashville
Central—Charleston-Huntington
Southwest—Dallas-Fort Worth
Midwest—Milwaukee
Western—San Diego

Chapters qualifying for an "Award of Excellence" were: (In addition to the above)

Albuquerque
*Atlanta
*Central Arizona
Central Indiana
Chattanooga
*Cleveland
Columbus
*Dayton
**Evansville
Long Island
Los Angeles
Mid-Hudson
Metropolitan New Jersey
Niagara Frontier
Oklahoma City
Pensacola
Savannah
**Southern Ontario
Tulsa
York

*Second consecutive award.
**New chapters this year.

AKRON CHAPTER

Robert L. Griffiths, Superintendent of Power and Processing for Diamond Crystal Salt Company was elected president of the Akron Chapter. He succeeds Ralph F. Fix, Firestone Steel Products Company Staff Industrial Engineer who was appointed to the Board of Directors together with Professor Michael Bexbatchenko of Akron University College of Engineering.

William R. Schultz was elected vice president; Joseph A. Dumbauld secretary; Jack N. Ross, treasurer; and Robert A. Henderson, sergeant at arms. James T. Austin was appointed to the Board of Directors to fill the one year term vacated by Garvin W. Timms.

LOUISVILLE CHAPTER

Mr. Norman K. Morrison, Product Manager of Executone, Inc., was guest speaker for the April meeting at University Center on the U. of L. campus.

Mr. Morrison's topic, "Centralized Timekeeping", touched on an area of potential savings that has been long recognized by the majority of our members. The larger than usual turnout was an indication that as Industrial Engineers our search for better and more economical methods will not by-pass indirect shop or clerical personnel. Affiliation with the National Association of Accountants and AIIE was reflected in Mr. Morrison's discussion, as he displayed a knowledge of the cost problem and had a proposal for its solution. The equipment demonstration was interestingly presented and brought out many questions after the discussion. We are indeed grateful to Mr. Samuel Stern of Executone's Louisville office for his generous cooperation.

The Louisville Chapter's Annual Spring Conference was held at the University Center on April 10. The topic, "Job Evaluation", was well presented and well received. Our hats are off to Herb Rogers, conference chairman, and his committee. A word of praise should also go to James Kershner, Ralph Blakely, and Ed Thoben.

At the Annual Banquet of the Louisville Engineering and Scientific Societies Council, held on May 14 at the Kentucky Hotel, a $550.00 scholarship award to the Speed Scientific School was presented to Robert M. Gregg, a senior at St. Xavier.

Ronald Rickwald of the Naval R.O.T.C. has been chosen as one of the fifteen outstanding military engineers of the 52 colleges in the U.S.A. Ronald is the son of Raymond Rickwald, senior member of our local AIIE.

METROPOLITAN NEW YORK CHAPTER

The Metropolitan New York Chapter established two student awards: The Walter Rautenstrauch Award in memory of the founder of the Industrial Engineering Department at Columbia University in New York, and the David P. Porter Award in honor of Professor Porter of the Industrial Engineering Department of New York University. These awards were given to two outstanding undergraduate students of the respective schools at the graduating exercises and at the student society meeting. Mr. Ernest Bender, evening student at the College of Engineering, New York University, received the David P. Porter Award, and Mr. Richard Zapolin received the Walter Rautenstrauch Award at Columbia University.

MID-HUDSON CHAPTER

The Mid-Hudson Chapter was the first AIIE Chapter to exceed its quota for the United Engineering Center Building Fund. The Chapter attained 173 percent of its goal. Congratulations were extended to Mr. Lloyd Smiley and his committee by Mr. W. Vallette, Northeast Regional Vice President. He awarded a delegate-at-large assignment to the chapter for the 10th Annual AIIE Convention.

The Annual Ladies Nite dinner meeting was held in April at the Nelson House in Poughkeepsie, New York. Professor H. A. Cozzens, Jr., of New York University addressed the group. His talk "Your Wife—An Industrial Engineer by Intuition" was lively and entertaining.

The March meeting featured a "Case History Night". Chapter members presented projects from their work experience. Mr. R. W. Reip, Hercules Powder Company, discussed a methods study and the introduction of a group incentive plan. The second discussion by Mr. K. C. Griswold, Sonotone Corporation, covered work measurement. He explained the justification, the methods and the effectiveness of work measurements at his company. Mr. L. G. Smiley, Western Printing and Lithographing Company, spoke on the methods of determining the rate of return on assets.

Dr. Adam Abruzzi, Professor, Stevens Institute of Technology, addressed the February meeting. His talk "Work Measurement" was an interesting and informative discussion of management and labor in this field from the neutral position of an educator. At the January meeting Mr. J. L. Krumpleman, Military Products, International Business Machines, presented a talk on operations research. The application of operations research and the development of a sample production schedule provided the basis for Mr. Krumpleman's talk.

Mr. D. A. Leard was presented with the first annual President's Award of the Mid-Hudson Chapter, in recognition of his outstanding work as Chairman of the Program Committee and Treasurer during the chapter year of the chapter. Mr. W. D. Wilson, President, made the award.

The Mid-Hudson Chapter was represented at the Atlanta Convention by Mr. W. D. Wilson, President, as Chapter Delegate and Mr. W. E. Walker as Regional Delegate-at-Large.

The May meeting featured Professor R. Contini, New York University, as guest speaker. His subject was "Human Engineering in Industrial Engineering". The Mid-Hudson Chapter meets on the third Thursday of each month in Poughkeepsie, New York. Society members in the area are invited to attend our meetings.

ROCHESTER CHAPTER

Activities in the Rochester Chapter have expanded at a very favorable rate as indicated by a larger membership and greater member participation in the various projects the chapter has under way. For the 1958-59 season we adopted as our theme "Progress Is Our Most Important Problem," this to be our guiding philosophy as Industrial Engineers in business and in civic affairs as well.

Chapter meetings, held at the University Club, are preceded by a social hour and dinner. The Program Committee headed by Harry Davis, Kodak Park Works, put together a diversified program apropos of the general theme. At the regular meetings we had such outstanding speakers in their field as Drs. E. H. Bowman and Harold C. Passer, Dean Gordon B. Carson, past AIIE President, and Professor Edward V. Krick.

Several new program ideas were advanced this year. Industry Day was held in November. Instead of a regular monthly meeting the Chapter went on tour of the Telecommunications Division of Stromberg Carlson Division, General Dynamics. Following dinner in the plant cafeteria and a short business meeting, Mr. Clarence Van Epps, Director of Manufacturing for the Electronics Division, gave us some insight into the problems and costs involved in today's missile program. In February the meeting took on a new flavor—we held Ladies Night. Members' wives were invited to attend the entire evening and the speaker, Mr. E. H. Plant, Director of Training, Eastman Kodak Office, directed his talk to the ladies. His subject—"So You Married an Engineer." This meeting was so successful that it is planned to adopt Ladies Night as an annual affair.

At the April meeting officers for the 1959-1960 season were announced. Robert W. Sparkes, Stromberg Carlson Division, General Dynamics will serve as president; Richard H. Woodward, Bausch & Lomb Optical Company, vice president; Nick Kralles, Eastman Kodak Company, secretary; and Mary Rita Merkel, Bausch & Lomb Optical Co., treasurer. Also elected to fill expired vacancies on the board of directors were Freeman C. Lewis, Taylor Instrument Co. and James E. Sundstrom, Eastman Kodak Company.

The May meeting was given over to presentation of the Rochester Chapter Technical Achievement Award. The winner of the award was Mr. Melvin R. Witmer, a member of the Industrial Engineering Division of Eastman Kodak Co. Mr. Witmer read his paper "Industrial Engineering At the Department Head Level" which presented mathematical techniques for solution of maintenance and inspection problems. The award was presented by National President George H. Gustat. The competition was inaugurated this year. Eligibility was not limited to chapter members but was open to all practicing engineers having some contribution to make in the field of Industrial Engineering.

Among our additional activities during the season was joint sponsorship with the Syracuse Chapter for the First Northeastern Regional Conference held at the Hotel Syracuse, Syracuse, N.Y. on October 30-31. The program and publication of proceedings were the responsibility of the Rochester Chapter, Robert C. Edwards, Bausch & Lomb Optical Co., acting as chairman.

Community projects have received considerable chapter support, perhaps the most outstanding being the Annual Science Fair sponsored by the schools with the support of the Rochester Council of Scientific Societies of which our chapter is an active member. The Fair is an open competition for students at all levels. Through its various member societies the council has developed the basis for awards and each year furnishes panels of judges needed for intramural and final competitions. Prizes include scholarships, cash awards and medals.

SAN DIEGO CHAPTER

The following article, by L. R. Recht, President, San Diego Chapter, AIIE, was published in the May 1959 issue of Western Industry and is reprinted due to its excellence and pertinence.—Ed.

TECHNICAL CHAPTERS—ARE THEY REALLY EFFECTIVE?

How you can improve yourself as a member and improve your chapter . . .

Are chapters of a technical society really effective from a professional standpoint? Or are they merely sources of quasi-social gatherings where engineering diletantes convene in an atmosphere of tolerant boredom? Are they generally intended to merely enforce unofficially the ethical obligations of the professional man?

TABLE 1

Anyone you know in this table? It tells some of the common symptoms, causes and cures for the ills of Western technical chapters.

SYMPTOM	CAUSE	CURE
Minority controlling cliques	Don't care attitude of many members (semi-nepotism)	**Frank evaluation of your own participation**
Members-in-name only	Laziness, flagrant featherbedding (nothing else)	**Assign tasks with specific responsibility**
Engineers-by-title only	Lack of real educational or professional background (quality)	**Clean your house, weed out the pseudo "engineers"**
Complaints, all varieties (dues, meals, prices, etc.)	Pure alibis, usually for lack of interest (reflects the "what's in it for me" attitude)	**Improve upon each item (but also consider the source, much of this is just childish quibbling)**
Irregular/poor attendance	Poor programming, lack of fellowship, indifference	**Dynamic programming, telephone contacts, drop out the frequent offenders (drastic but actually no loss)**
Avoiding committee or task assignments	Again laziness, indifference ("let George do it" attitude)	**Develop fellowship, create sense of belonging, make it a group effort**
Shabby/varied meeting locales	Lack of pride, petty penny-pinching, poor planning	**Develop prestige, create a feeling of pride, get "executive" at least in appearance**

And what about the Chapter member? Is he a hard-driving, alert, vigorous, scientific crusader dedicated to the welfare of man? Or is he an indifferent, unresponsive typical "joiner"—motivated mainly by selfish personal interests rather than group esprit de corps?

Frankly, as the saying goes, *it is now high time for all good engineers to take a hard look at some of the answers to the above questions.* A little individual soul searching at the same time might prove beneficial. And, while we are covering this particular waterfront, let us not overlook the innocuous hanger-on, the perennial free-loader in the background—in other words, that engineer or technician who contributes absolutely nothing to over-all professional advancement by the simple expedient of merely not belonging to any organized professional group. Surprising as it sounds, a substantial number of engineers and technicians fall into this latter category.

Is there truly a problem in this area? Are Chapters really such

a complex form of human association? *A straight-forward honest answer certainly would have to be in the affirmative.* How do we recognize the problem? Let's take the grass roots approach and look at some of the causes and effects. Table 1 lists some of the symptoms that must have a familiar ring:

What's that? Exaggeration? Gross distortion? Not representative? Just poppy-cock? Well perhaps, but you'll have to admit—if you're honest and uninhibited—that *we are shooting pretty close to the bull's eye.* We gain absolutely nothing by kidding ourselves or by reprehensible evasion.

The Average Guy—A Driving Force

Let's look at our Chapter personnel first, *The "average" member can become a driving force*—a prestige guy with pride in his organization and his associates—a bona fide quality representative of his profession. How can this be done? Well, it isn't easy—neither does it call for super-human endeavors.

First, make sure he wants to belong. This is tremendously important—no use drilling in a dry hole. *Secondly, create a feeling of desire on his part for personal prestige.* This can be accomplished in part by obtaining good publicity for the Chapter, and the members thereof—in the newspapers, company publications, technical journals, trade magazines, etc. This is hard work, but it will pay surprisingly big dividends.

Next, give him a specific task to accomplish and insist on top performance no matter how insignificant the assignment.

NOW, reward his efforts in some tangible manner—let his company, his wife, his associates know of his fine performance. *Don't slip up here*—it's the wrap-up of the job, and how well you do it, that pays off. *If you do this,—and no more—You will have won the game with the MEMBER.*

Creating Chapter Prestige

Now, let's examine our Chapter's official family. The "average" Chapter can be a vibrant entity—progressive, proud, strong, and respected. How can this be done? Again, it isn't easy—and it doesn't call for herculean efforts. But—it's a tougher chore than your curative prescription for the "average" member.

To start with, we must create Chapter prestige. Again, make sure that this is wanted by the majority. *Lots of the boys are just looking for an excuse for a "night out."* Strong language? Perhaps—but at least we're calling the shots as we see them (and know them) from analyzing hundreds of meetings of all kinds. And, please, no scholarly letters to the contrary—you'll just be cluttering up the waste basket.

Chapter prestige begins by insisting on a dignified and appropriate meeting place. If you are going to be in the major leagues, then by all means look like a big leaguer. Add to your prestige by making it difficult to belong. You lose face when every Johnny-come-lately can ease in with no strain. Screen your new applicants—make sure they intend to *participate.* Ten demerits for the Chapter that mistakes size for quality. *One sincere member is worth ten dabblers.*

Secondly, concentrate on a truly constructive and outstanding program. Make your members want to come to your meetings. Insist that your Program Chairman firm up each meeting, in its entirety at least six weeks in advance. Outline an annual program at the start of your Chapter year—clear this with your Executive Board—ask your members what they want to hear or do. *If you are going to pull your member away from the comforts of his home, his television, his books, his hobbies—then you owe it to him to put on a good show.* Again, please, no pious platitudes about how unnecessary this should be for the "true-blue" professional.

Next, *demand* that your meetings be top quality. Create a real atmosphere of belonging—of fellowship. Vary your seating arrangements; make your members move, around—perhaps have an "honor" table, besides the head table for special guests, etc. Insist on a good dinner (prime rib, steak, lobster)—pay more if need be—but avoid cheap, hurriedly served, circuit-banquet type meals. Make the dinner a high spot of your meeting rather than a routine detail. This will impress your guests, your speakers—and should eminently satisfy the inner man. Pass around good cigars occasionally after the meal, or a good liqueur, with the Chapter picking up the tab.

Finally, *direct that a concise, hard-hitting, rigidly-adhered-to time schedule be followed*—start on time—end on time. This shows respect for the personal time of your members; and you will be pleasantly surprised to discover how much favor this finds with the regulars. If you have business to transact, prepare brief handouts that the members can peruse during the meal—this will expedite decisions later on. Prolonged meetings, like long-winded speakers, will sound the death knell for many a Chapter. There is a boldness of action required here that is an implicit responsibility of our stewardship.

Remember, the above are *essential* prerequisites for a successful Chapter; like the phrasing in the song "they go together like a horse and carriage." These are basic responsibilities of the Chapter Officers and the Executive Board. If they do any less, then they simply aren't measuring up.

Dealing With The Chapter Extrovert

Since we are scrutinizing the entire picture—*let's touch briefly on an unsavory item. What about the Chapter extroverts?* These are the choleric characters with the hollow log or raucous voice, the constant complainer, the dues delinquent, the work evader, the meeting disrupter—well, I'm sure you recognize the type. Every Chapter has them—in fact, every organization that I've ever seen has its share of one sort or another. I guess this is to be expected—though not necessarily a requirement. Thank goodness they are a small minority, albeit a very disturbing element. There are two alternatives as we see it.

1. *Get rid of them, or*
2. *Tolerate and ignore them.*

You are gambling with the welfare of your Chapter if you go altruistic and choose number two. Don't use your Chapter as a corrective institution for adolescent adults—leave this to the AA and other more qualified organizations.

Perhaps at this point you feel like asking "Why this crusade—why all the excitement?" It's academically simple, based on these personal assumptions:

1. *That scientists, engineers, and technicians are going to be the salvation of this wonderful country of ours.*
2. *That the hard core of dedicated professional men needs the full support of all their associates.*
3. *That the "average" Chapter member can be revitalized—that his latent talents can be brought to the surface.*
4. *That any Chapter can be successful with proper planning.*
5. *And, particularly, because of an innate selfish desire on our part to see the engineer come into his own.*

Summary

In summarization let's evaluate our findings: First, let me emphasize that there are many, many fine technical and professional Chapters—really crackerjack outfits—all of them affiliated with national organizations whose national officers reflect the highest qualities of integrity, sincerity, and professional dedication. BUT—there most certainly *is* a local or field problem that needs facing up to. It concerns the tragic ineptness or lack of professional fervor on the part of *many* Chapters which leads them into a quagmire of futility. This is partly the fault of the Chapter—stemming from an obvious lack of positive leadership. In addition, it is the fault of

the Bill Browns and Harry Smiths—the indifferent, lazy, irresponsible members (or even worse, non-members) who want utopia (professional recognition) without being willing to work for it.

Is there any panacea for all of this? Yes—within the perimeters of the suggestions set forth above. Your Chapter can be top grade—but it will take hard work, lots of it. You have to think progressively and use your "work-horse" as a catalyst. Above all, it depends to a large extent upon how well the Bill Browns and Harry Smiths measure up. Believe me, we're just fooling ourselves if we think otherwise.

BOARD OF TRUSTEES' MEETING

BILTMORE HOTEL
ATLANTA, GEORGIA
MAY 15, 1959

The Board of Trustees of AIIE is the official governing body of your organization. This group meets to conduct business for you twice a year. The official minutes of the May Board of Trustees' meeting are published in the Journal *to keep you informed of AIIE activity.*

The meeting was called to order by President Gustat at 9:23 A.M. Among those in attendance were: George H. Gustat, President; Frank J. Johnson, First Vice President; Floyd J. Titler, Executive Secretary; Ralph W. Updegraff, Treasurer; Lee S. Whitson, Vice President, Midwestern Region; William J. Vallette, Vice President, Northeastern Region; David G. Dall, Vice President, Southeastern Region; Delmar W. Karger, Vice President, Central Region; John T. Elrod, Vice President, Southwestern Region; Jack F. Jericho, Vice President, Western Region; James D. Nordahl, Board Member-at-Large; Frank F. Groseclose, Board Member-at-Large; Warren E. Alberts, Board Member-at-Large; Alex W. Rathe, Board Member-at-Large; Howard P. Emerson, Past President; Eugene H. MacNiece, Professional Relations Committee; Robert N. Lehrer, Editor-in-Chief, *The Journal of Industrial Engineering;* Alan J. Levy, Editorial Board, *The Journal of Industrial Engineering;* William Hodson, Chairman, Task Force on Industrial Engineering Classification in Civil Service; Vernon D. Foster, Director of National Meetings; Andrew Schultz, Jr., Director of Research; P. M. Dodson, General Chairman, 1960 AIIE Conference and Convention Committee; Henry M. Owades, Director of U.E.T. Affairs; Chester Zakrzewski, President, Detroit Chapter; Thomas Woolard, President, Chicago Chapter; Elio Rotolo, President, Metropolitan New Jersey Chapter; and Don A. Trenwith, Business Administrator.

1. *Minutes, October 11, 1958 Board of Trustees Meeting*—Dr. Rathe asked that the minutes of this meeting be changed to read as follows:

3e2. Second paragraph to read:

"Mr. Olsen, who is chairman of the AIIE Task Force studying unity in the profession, made a few explanatory statements and said that this task force had been polled on several alternatives and that these principles were evolved from them which are presented to the board for consideration:"

3e2. Last paragraph to read:

"At the conclusion of this report, Dr. Rathe moved that 'The AIIE Board of Trustees approve these principles and as a recommendation a minimum position on unity to the effect of supporting a merger between EJC and ECPD.' Motion was seconded by Mr. Jericho and passed unanimously."

Mr. Johnson moved that the minutes as changed be accepted. Motion seconded by Mr. Vallette. Motion passed.

2. OLD BUSINESS

2a1. *United Engineering Center*—Mr. Henry M. Owades presented additional information on the progress of the United Engineering Center construction. He noted that a letter had been received from the coordinator of the project regarding space allocation and floor plans.

2a2. *Fund Raising Report*—The following report was made by Mr. Owades and Dr. Alex W. Rathe. At the present time about $26,800 or 38% of the total of the $70,000 quota has been pledged by AIIE members. The following percentages by region have been pledged to date: Central, 27%; Western 18.5%; Southeastern, 13%; Northeastern, 43%; Midwestern, 30.4%; Southwestern, 24.2%.

Some chapters have not even yet started their fund raising campaign. The plan to request the outgoing Vice Presidents of the regions to continue their efforts and to maintain their direction of this drive was reviewed and approved. The chapters are urged to set up a weekly reporting system within their organization so that the progress of the fund raising committee members will be reported to the chapter president regularly.

Additional pressure must be exerted by all the chapters who have not yet met their quota. The fund raising committee is sending a semi-monthly report letter to all those who are responsible for the drive.

2a3. *Tax Classification Status*—President Gustat asked that the Board of Trustees be brought up-to-date on the status of the tax classification application.

Dr. Rathe stated that correspondence had been exchanged with the attorney representing AIIE and the United Engineering Center office. Some of the material covered in these letters has not yet been fully completed. The question arose about whether or not our status was at the present time 501 (c)(6) or 501 (c)(3).

Mr. Trenwith reported that in the opinion of our attorney, we were still in the classification of 501 (c)(6). Until such a time as our application for 501 (c)(3) status had been approved, we will remain in a (c)(6) classification. The actual application for the 501 (c)(3) status cannot be made until we have operated a year under the changed purposes clause of the constitution. Approval of 501 (c)(3) status will qualify our members for a tax deduction on all money contributed to the AIIE, make us fully eligible for occupancy in the United Engineering Center. Such status will also qualify us for tax exemption under the New York State real estate law. This condition must be met, along with our change in Federal Income Tax status, in order that we will be qualified for occupancy in the United Engineering Center.

2b. *Chapter Development Program*—Mr. Johnson reported that 27 Senior Chapters were being recognized this year and that, for the first time, regional winners would receive special plaques and recognition.

The current chapter development program got under way April 1, 1959. An additional 30% increase in the number of chapters participating is predicted. The new chapters getting into the program are improving their scores by improved attention to the details of the program. Chapters are writing the director of the program and suggesting additional items to be considered.

The incoming Vice Presidents of the regions are asked to communicate additional suggestions to the director to be added to the program in coming years.

Several questions were discussed regarding the possibility that the chapters are being asked to complete too much paper work. This requires additional study.

A suggestion that each chapter be put on a common fiscal year and officer year was made. Most of the chapters have different

dates, a few of them coinciding with the National's fiscal year. A fixed date for each of the chapters to observe would aid in the preparation of annual reports.

President Gustat suggested that the incoming First Vice President, Mr. Jericho, could study this situation.

A note was made of the fact that January 1st was a bad date for the collection of dues.

In line with the preparation for the material for the Annual Report, special report forms for use by the chapters and for various committees are being developed. The reports should be submitted at least two months before the Annual Conference for use in the preparation of the AIIE's Annual Report.

2c1. *1959 Conference and Convention Report*—Mr. Johnson reported that the previous high registration record held by the New York Conference had been surpassed by this year's meeting. A larger percentage of the attendees are purchasing tickets for the meal functions. The special dinner scheduled for Aunt Fanny's Cabin had been sold out.

Costs will be higher for this conference because of the increased distribution of the program and the extra printing costs, over 37,000 brochures having been mailed out. Mr. Johnson was of the opinion that the conference would show a profit regardless of the increased cost. The conference committee has promised the final report by July 1, 1959.

Additional aid in the selection and rating of speakers for National and Regional Conferences by a national committee specifically established for that purpose was discussed. It will receive further consideration.

2c2. *Proposed Change in Meeting Schedules*—Regarding the possible rescheduling of the Board of Trustees meeting and the convention in their relation to the two days of conferences was discussed. A survey is being taken of the attendees of this conference to determine their feelings in this matter. The report from the survey will be available within a few weeks.

Dr. Rathe moved that the board direct the incoming Executive Committee to make the necessary decisions as to the scheduling of these meetings in time for the Dallas Conference and Convention. Motion seconded by James Nordahl. Motion passed.

2d. *Journal Advertising*—This item was tabled at the time of the morning session so that it could be discussed when Robert N. Lehrer, Editor-in-Chief of the *Journal of Industrial Engineering* could be present.

After luncheon the *Journal* was represented by the Editor-in-Chief, R. N. Lehrer and Alan J. Levy of the Editorial Board.

Mr. Titler stated the position of the National Headquarters. Something must be done about increasing the advertising in the *Journal* so that the funds now being spent in this regard could be released for other AIIE functions. Mr. Titler said that the general feeling of the headquarters staff was that the *Journal* advertising program should be under the direction of the Editor-in-Chief and that additional agencies should be employed to cover other advertising centers than those represented by our current agent.

Considerable discussion concerned the fact that an unpaid staff cannot devote enough time to the task. Discussion of the past history of the *Journal* advertising and the problems involved followed. Dr. Lehrer suggested that there are other ways of supplementing the *Journal* income budget, perhaps increased circulation. Since the *Journal of Industrial Engineering* is not the only publication in the management field, there is considerable competition for advertising, especially from commercial publications.

Mr. Titler moved that the incoming President with the counsel and advice of the Editor-in-Chief, appoint a special committee to study the *Journal* advertising question, the committee to be established with the charge that this study needs serious and immediate attention. Mr. Johnson seconded the motion. Motion passed.

Mr. Johnson suggested that Dr. Lehrer and the Executive Committee discuss this matter further during June and take action so that a new plan may be well underway by October of this year.

2e. *Professional Relations Committee Report*—Dr. Rathe reported that the AIIE had been invited to make nominations for the National Science Foundation Board of Directors. Three men have been suggested for this nomination. They are: Dean Robert H. Roy of Johns Hopkins University; Dean Athelstan F. Spilhaus of the University of Minnesota; and Dr. Mervin Kelley, President Emeritus of Bell Telephone Laboratories. Of the three nominated, two are to be elected.

Mr. Updegraff moved that the committee's report and recommendations be accepted for the nominations of these three gentlemen. Mr. Johnson seconded the motion. Motion passed.

Dr. Rathe passed out copies of a proposed definition of engineering that has been offered for comments by ECPD. Dr. Rathe reviewed the proposed definition, particularly in its relationship to our definition of Industrial Engineering.

Dr. Rathe moved that the Long Range Planning Committee be asked to study the definition and report their findings to the Professional Relations Committee by September 1, the committee to pass their recommendations on to the Board of Trustees in time for the October meeting. Mr. Titler seconded the motion. Motion passed.

Dr. Rathe reported that for the first time the AIIE has been invited to participate in the preparation of the Annual Engineering Management Conference. This year's meeting is to be held September 17 and 18, in Los Angeles, California. An excellent program has been planned for this year and the AIIE has joined with the five other principal engineering societies—ASME, AICHE, AIEE, AIME, and ASCE in this project. In past years, electrical and mechanical engineers have underwritten the losses as they occurred. There was a small loss connected with the Boston meeting because of inadequate preparation, costing each of the two societies about $200.00. Mr. Eugene MacNiece, our representative to the Engineering Management Conference, reported that good planning and budgeting could easily eliminate all possible losses from future meetings.

Mr. MacNiece suggested that after September, the AIIE make a definite statement of whether or not they wish to support this function financially, as well as aiding in the planning function. Our responsibility would not be in proportion to our membership in comparison to the others. The top risk involved might be in the neighborhood of $150 for any one meeting. This is a top level conference held once a year for specific and unique discussions of management of engineering functions.

The Board of Trustees gave Mr. MacNiece a vote of confidence so that he could state the AIIE's probable position in advance of the fall Board of Trustees meeting.

Dr. Rathe asked for a discussion of the duplication of effort on national, regional and local levels. President Gustat suggested Dr. Rathe give his recommendations to the group making a general study of the AIIE functions, under the direction of incoming First Vice President Jericho.

Mr. Titler moved that the Board of Trustees and the Executive Committee make the fullest possible use of all AIIE committees, that, whenever time permits, the advice and counsel of any particular committee be requested prior to the time either of these bodies contemplates considering and acting upon matters of concern to that committee, and that the result of such consideration and action be communicated to the committee involved by letter from the executive secretary. Motion seconded by Col. Groseclose. Motion passed.

The board stressed that the Board of Trustees and the Executive Committee should at all times be properly informed and that all committees should be cautioned to consider all their actions and recommendations in relation to what other committees or functions of the AIIE might be concerned.

Mr. Warren Alberts speaking for Mr. Richard Forberg, Chair-

man of the Professional Development Task Force of the Professional Relations Committee, reviewed the "Program to Promote the Professional Development of the Young Industrial Engineer" for the Board of Trustees.

The purpose of the program is to aid, spark and direct the graduating engineer in the first five years of development, by (a) giving every graduate engineer with less than five years experience, information on the program along with other selected material, (b) do the same for each graduating student member and other graduating Industrial Engineers, (c) work with ASEE and ECPD to provide similar material to all graduating engineers.

Each chapter should designate one person to follow through in promoting the five year plan in its locality and provide interested individuals with the proper material. Getting the young engineers together for improved understanding of the goal of the engineering profession as a whole would be a part of the program.

The cost of the program is estimated at around $730 and the committee is recommending that the board approve $850 for the next fiscal year.

Responsibility for implementing this program and selecting the material would be assigned to the Professional Development Task Force of the Professional Relations Committee. National Headquarters will be asked to obtain names of graduates each year.

Mr. Trenwith states that some problems may arise in the distribution of the material as reported by the members of the Council of Engineering Societies Secretaries.

In many cases less than 20% of members receiving such material even open it and read it. Mr. Trenwith suggested that stress be placed on personal contact where senior chapters are available to take over the activity. Additional problems of distribution of material through the student chapters may arise.

Mr. Updegraff moved that the report submitted by Mr. Alberts for this task force be accepted, with the understanding that the committee will work further on the mechanics of the distribution of the material. The Professional Relations Committee is to include the expense involved in their budget request for next year. Motion seconded by Mr. Jericho. Motion passed.

Dr. Rathe asked the Board of Trustees to refer to the report of the Professional Relations Committee's Task Force on Professional Standards. Dr. Rathe suggested that the following action be taken:

2e1. That a group be appointed to write appropriate supplements to the ECPD Canons of Ethics to restrict specific violations of ethical practice in Industrial Engineering, e.g. discouragement of the undignified "hard sell" technique employed by some consultants might be a target of such supplementary provisions. Although section 2 of the Canons touches on this, it is not considered sufficiently pertinent.

A. The same group should be charged with the responsibility of interpreting the Canons and determining when a violation exists in fact.

B. This group should also have an enforcement function and should recommend disciplinary action or expulsion from the institute to the board for confirmed and documented violations.

2e2. To preserve the identity of the Industrial Engineering profession, a study group must be commissioned to inventory known Industrial Engineering functions for inclusion in the standards.

A. With these functions clearly in mind a committee on Industrial Engineering education should draft standards of education for undergraduates, graduate instruction for Industrial Engineering Bachelors, Masters, and perhaps Doctorates. These educational standards should be fully set forth in the main body of the professional standards.

2e3. Select a group to review membership qualifications and make revisions where necessary before stating them in final form through the standards.

2e4. Appoint a group to determine the feasibility of examinations for admission into AIIE and for the possible use of State Boards for determining professional competence for state registration.

2e5. Form an editorial committee to make needed editorial revisions and to assemble the finished statement into an attractive brochure to be given the widest practicable distribution.

Dr. Rathe moved the adoption of the report and implementation by the new president. Motion seconded by Mr. Vallette. Motion passed.

Mr. William Hodson made a report as Chairman of the Task Force on Industrial Engineering Classification in Civil Service. The Civil Service has welcomed any aid the AIIE can give them toward setting up job descriptions for Industrial Engineers within the Civil Service framework. In order for their analysts to make proper use of such material they must have it by June 1, 1959. Mr. Hodson told the Board it was regrettable that the Board and other committees of the AIIE could not have more time to study the proposals of his task force, but time was too short.

Various members of the organization had been asked to study the report prior to the Board of Trustees Meeting and the following changes were suggested:

1. "Operations Research"—should have a separate heading and a more detailed description.
2. "Organization Planning and Special Management Studies" in same category and should be one of the first listings, rather than the last.
3. The material should include the idea: that Industrial Engineering is a dynamic science and art, and in continual state of change. It should be described as of the moment, recognizing full well that it is an ever changing field.

Mr. Hodson pointed out that if this material is not ready for the Civil Service Commission by June 1, the entire description of Industrial Engineering functions would be written by a less qualified group rather than by Industrial Engineers. This draft to be presented to the Commission will be reviewed and changed by the Civil Service Commission. The Board of Trustees will have an opportunity to review the final draft of the Civil Service Commission's report before it is released.

Mr. Updegraff moved that the information be given to the Civil Service Commission with the above changes. Motion seconded by Col. Groseclose. Motion passed.

2f. *Other Old Business*—None

3. NEW BUSINESS

3a. *Membership Report*—Mr. Titler presented the membership report representing the membership of the AIIE as of the first of the month. The Board of Trustees discussed the membership growth and the low rate of drop-outs for non-payment of dues during the past year.

The board was informed that increased activity by the chapters and the Vice Presidents of the regions, plus additional mailings from National Headquarters had considerable effect on lowering the rate of drop-outs this past year. In addition, the improved financial picture of business was thought to have had considerable effect. It was noted that one of the main reasons that members were dropping out or resigning was that they were being promoted to purely administrative positions or otherwise transferring out of the field of Industrial Engineering.

Col. Groseclose asked about our membership screening process. In a project he has undertaken at Georgia Institute of Technology, he had noted that some applicants for positions, while being listed as members or associates of AIIE, did not seem to fulfill the membership requirements. Col. Groseclose has been asked to give more details on this to National Headquarters so that any indicated corrective action could be taken immediately.

3b. *Financial Report*—Mr. Ralph Updegraff presented the finan-

cial report as of the end of April. Copies were provided all board members attending the meeting. Mr. Updegraff noted for the board that the income and expense items listed were close to budget and that there were no particular problems at this time.

Dr. Rathe raised the question regarding what income was indicated on the budget as "Conference Income" for the year. Mr. Updegraff replied that both the Atlanta Conference and Los Angeles Conference income were included in the figure.

President Gustat called to the 1960 Conference Committee's attention (their representative at this meeting, Mr. P. M. Dodson) that their committee should start making regular financial and budget reports during the coming month.

3c. *Proposed Chapter Constitution Change*—This item, listed on the agenda for the meeting was deferred to the next meeting of the Executive Committee.

3d. *1960 Conference and Convention Report*—Mr. P. M. Dodson reported on the progress made to date by the 1960 AIIE Conference and Convention committee. The 11th Annual Conference and Convention will be held May 12, 13 and 14 in Dallas, Texas. Hotel accommodations have been arranged. Mr. Dodson remarked that they were getting considerable information about the solution of problems that will arise, from the experiences of the Atlanta Conference and Convention committee.

President Gustat inquired as to whether or not the 1960 Conference Program Committee was arranging with Dr. Schultz, Director of Research, AIIE, for aid in establishing technical sessions. The committee stated that such cooperation was underway and some technical sessions had already been scheduled. The proposed program is to be made available to members of the Board of Trustees during the coming months for review and comment.

3e. *Location of 1961 and 1962 Conferences*—Mr. Vernon D. Foster presented the bids from four chapters to host the 1961 AIIE Conference and Convention. The chapters bidding were Detroit, Chicago, Metropolitan New Jersey, and Rocky Mountain.

The Chicago Chapter withdrew their bid.

Mr. Titler moved that past procedure be adhered to, each chapter being allowed to talk three minutes regarding their bid, after which questions could be asked by members of the Board of Trustees. Motion seconded by Mr. Johnson. Motion passed.

The Detroit Chapter was the first to make their presentation, represented by Mr. Zakrzewski.

The Metropolitan New Jersey Chapter, bidding for the Conference and Convention to be held at Atlantic City, was represented by Mr. Rotolo.

Representing the Rocky Mountain Chapter, Mr. Jack F. Jericho, Vice President of the Western Region, AIIE, stated that even though the bid for the 1961 conference as previously presented by the Rocky Mountain Chapter, was a serious effort to have the meeting awarded to them, they were at this time withdrawing their bid for the 1961 conference.

Mr. Lee Whitson, Vice President of the Midwestern Region, AIIE, stated for the record that Chicago, who had previously withdrawn their bid, should be considered at some appropriate time in the future to host a conference and convention and that no prejudice should be involved because of the reasons surrounding the withdrawal of their bid. The Board of Trustees was in agreement with this statement.

The board discussed the possibility of the awarding, at this time, the 1962 conference and convention site. It had been the intent to award the 1962 meeting in addition to the 1961 meeting at this time. It became obvious that because of the provisions of the AIIE By-Laws, Article 4, Section 6, that this was impossible. In addition, no other chapters, except the four who had originally submitted bids for the 1961 conference, had any opportunity to present a bid for the 1962 conference.

Mr. Titler moved that this Board of Trustees Meeting select only the location of the 1961 conference. Motion seconded by Mr. Vallette. Motion passed.

The Board of Trustees then voted on the awarding of the 1961 conference. Only two chapters were considered in the final vote. A clear majority of the board members voted in favor of holding the meeting in Detroit in 1961.

Mr. Titler moved that the Board of Trustees at their meeting to be held at the 1960 conference and convention, select sites for the conventions in 1962 and 1963. Motion seconded. Motion passed.

Professor Emerson moved that this Board of Trustees amend the AIIE By-Laws, Article 4, Section 6, to add "s" after the word site, and insert "and/or three," the section to read: "selection of the sites of the National Convention two and/or three years hence shall be made by the board . . . etc."

(This sentence now reads: selection of the site of the National Convention two years hence shall be made by the board . . . etc.)

Amendment motion seconded by Dr. Elrod. Motion passed. 11 voting for the amendment, 2 voting against the amendment.

3f. *Other New Business*

3f1. *Regional Conference Deficit*—Mr. Lee Whitson reported on the recent conference held by the Midwestern Region, AIIE, that had been hosted by the Chicago Chapter. The technical portion of the conference was extremely good. However, the meeting has resulted in a financial deficit. A discussion of the responsibility of the national organization brought out that some of the expenditures for the meeting were forbidden by the provisions of the AIIE Conference Manual. After a study of these expenditures, and recognition of the fact that the Chicago Chapter was well able to support half of the deficit that could be recognized, the following action was taken:

Mr. Nordahl moved that the Board of Trustees authorize the sending of a check for $541.02 to the Chicago Chapter as the national share in the loss incurred by this conference, and that, if the national organization is to continue sharing in the profits and losses of these meetings, more specific controls be established to help in preventing future occurrences. Motion seconded by Mr. Titler. Motion passed.

3f2. *Speakers Bureau for National and Regional Conferences*—Dr. Andrew Schultz, Director of Research, AIIE, proposed to the Board of Trustees, that the AIIE set up a continuing committee to study and recommend programs and speakers to be used at National and Regional Conferences. Many times the local groups hosting such meetings were not familiar with some of the speakers invited. In addition, since our policy prohibits paying speakers, this somewhat limits the speakers who may be available to us.

Dr. Schultz noted that speakers will not be able to attend all meetings to which they are invited and naturally will give their attention to those that will add most to their prestige as an individual. Since the AIIE is a young and smaller organization, then we have some difficulty in offering the recognition that these speakers can attain from attending the meetings of some other societies.

Dr. Schultz believes that a more formal setup will better protect the organization and its reputation in the profession. We need to take special care to have program content and speakers who will clearly meet our needs and objectives so that we can improve the quality of our presentations each year.

Mr. Titler suggested that such a special committee as proposed by Dr. Schultz might be included in the study now underway by the incoming First Vice President, Mr. Jericho, the results to be included in the Conference Manual. This study should be concluded in time to be of value to the Detroit Conference and Convention Committee.

3f3. *October 1, 1959-60 Budget*—Mr. Updegraff stated that a letter will soon be going out to all people who will be serving as board members, directors and committee chairmen, to submit the budget for the next year. The replies to this letter should be returned to Mr. Updegraff by August 1, so that the budget may be perpared in time for the September Executive Committee Meeting.

In addition to the specific requests for the coming year, each

individual will be asked to submit a five year forecast so that the Financial Planning Committee can begin to function as charged by the President.

3f4. *Achievement Certificates*—Dr. Rathe brought up the question regarding achievement certificates that were formerly awarded by the organization. He asked that consideration be given to reinstating this custom as part of the honors and awards program in a more specific fashion than had been followed in the past.

Mr. Titler stated that the achievement certificate would be made a part of the list of awards and grants now under study. Mr. Titler suggested that the Vice Presidents of the regions should also submit any information that they have in this regard that should be included in the survey to make possible a more uniform approach on awards.

3f5. *Appreciation*—Mr. Johnson expressed his appreciation to the outgoing Vice Presidents of the regions for their fine cooperation. To the incoming Vice Presidents he proposed that the schedule for Board of Trustees meetings be changed from two to three; one meeting to be held on October 17, one in February, and one at the time of the conference in May, at Dallas, Texas.

Mr. Johnson asked that the incoming Vice Presidents make inquiry within their regions as to what can be done to encourage more regional meetings in place of some of the chapter conferences.

Adjournment—The meeting was adjourned at 5:00 P.M.

Next Meeting—The next meeting of the Executive Committee will be on Friday, June 19, 1959. The next meeting of the Board of Trustees will be on Saturday, October 17, 1959 at Atlanta.

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145 North High Street
Columbus 15, Ohio

INDUSTRIAL ENGINEERING OPPORTUNITIES

Position number	Industry, location		Travel?	Job classification number (See key)	Salary range $1,000	Qualifications required		
						Years of exp.	Age range	Remarks
17	Air Force	Ohio		11, 13, 31, 38, 42	8.8–	4½–		
41	Consulting	Ohio	×	10, 21, 31		5–7		
167	Weapons Systems	Wash. D.C.		50				Ph.D.
213	Air Force	Calif.		15, 32, 42, 43, 44, 53	7.5–	2½–	21–	Repair & Modification
273	Air Force	Utah		10	6.3– 7.5	2–		I.E. Degree
279	Air Line	Ill., Colo., Calif.		11, 13, 18, 41–43, 50–52, 70	5.0– 8.5	1–6		
308	Automotive	Pa.		19, 36, 38, 53	6.6– 9.6	4–6		
316	Mining	Nev.		10, 20, 30, 40	6.0– 9.5		21–45	
339	Automotive	Pa.		11, 13, 15, 16, 22, 23, 36	6.6– 9.6	4–6		
340	Automotive	Pa.		13, 14, 15, 16, 22	5.4– 7.8	0–2		
352	Air Force	Ohio		50	5.7–12.5			M.S.I.E.
362	Aircraft	Conn.		50	Open	1–4		Milit. & Industrial Exp.
370	Air Force	Ohio			8.8–10.0	4½–		
376	Education	Mass.					35–	
386	Hospital	Ala.		10, 30, 42, 53, 71, 72, 92	6.5– 8.0	3–5		M.S. Preferred
396	Administrative	Ohio		36, 37, 38	7.2– 7.8			
399	Pulp & Paper	Ala.		30, 40, 50		3–5	25–35	
406	Steel Prod.	Ohio		11, 36, 39, 41–48	Open	5–10	25–35	I.E. Degree
412	Consulting	Minn.	×	10, 30, 40, 70, 90	Open	5–10	30–40	I.E. Degree
414	Printing	Wis.		10	4.6– 6.0	0–3	21–	
419	Food Processing	Ill.		13, 15, 16, 38	5.7–	0–3		
422	Air Force	Ohio		50	7.5–11.6			
423	Air Force	Ohio		Broad	8.8			
424	Air Force	Ohio		Broad	4.5– 7.5			
429	Aircraft	Calif.		19, 33, 34, 36, 38, 42, 43, 54, 71	6.2–10.0	3–10		
431	Heavy Equip.	Ind.		10, 40	6.0–10.0	2–10	27–40	
433	Synthetic Fibers	Fla.		10, 32–34, 43	6.0– 8.0	2–5	24–35	
434	Synthetic Fibers	Fla.		10, 32–34, 43	5.7– 6.3		22–30	
435	Synthetic Fibers	Fla.		11, 19, 33, 34, 43, 48, 53, 81	6.0– 8.0	2–5	24–35	
436	Education	Puerto Rico		37, 53	5.4– 7.8			
437	Carpet Mfg.	Va.		10, 36, 38, 42, 43	7.0– 8.2	3–5		
438	Electronic	Tex.		81		3–5		Packaging Design Exp.
439	Electronic	Tex.		36, 38		2–5		Acct. Degree & Exp.
440	Electronic	Tex.		10				I.E. Degree
441	Electronic	Tex.		36, 38, 70		2–5	25–40	I.E. Degree—IBM 650
442	Electronic	Tex.		30			25–35	I.E. Degree

Position number	Industry, location		Travel?	Job classification number (See key)	Salary range $1,000	Qualifications required		Remarks
						Years of exp.	Age range	
443	Education	Mont.		Broad	Open			Work on M.S./Ph.D.
444	Heavy Equip.	Ohio		10, 17, 21, 23, 72		4–		
445	Dairy Products	Mass.		10, 42, 43	7.0–	5–		I.E. Degree
447	Synthetic Fibers	W.Va.		10, 20, 30, 91	Open	5–		I.E. Degree
448	Refining	Pa.		11, 70, 73	10.0–	10–		
449	Electronics	Mass.		30, 50, 70	6.0– 8.0	1–5		
450	Workshop	N.Y.		10, 38, 42, 43, 81		3–5		Supervisory Exp.
451	Garment Mfg.	M.W. & S.W.	X	10, 31, 42, 64, 65	6.8– 7.8	3–	25–35	
452	Aircraft Assy.	N.Y.		11, 13, 15	7.5–	4–		
453	Rubber	Canada		10	4.8– 6.0	2–	25–40	
454	Machinery Mfg.	Ind.		11, 30	6.6– 7.8	2–4	–32	
455	Machinery Mfg.	Ind.		43	6.6– 7.8	2–4	–32	
456	Machinery Mfg.	Ind.		40	6.6– 7.8	2–4	–32	
457	Electronics	Ind.		11, 15, 30, 91	9.0–10.0	5–10	30–40	
458	Mail Order	Ill.		11, 36, 38, 43, 92	12.0–14.0	5–10	32–38	
459	Paper	Pa.		11, 57, 42				Pulp & Paper Ind. Exp.
461	Paper	Ohio		10, 20, 70	–13.0	3–	–45	Container & Packaging Exp.
462	Navy	Alaska		48, 71	11.0–14.2	3–5		
463	Gen. Construction	Tex.		11, 13, 18, 33, 34, 36, 43	5.4– 6.6	1–	–30	
464	Consulting	N.J.		10, 20, 32–34, 42, 43, 54, 71–73, 92	8.0–12.0	5–	30–36	I.E. Degree
465	Consulting	Mass.		General		15–20		
466	Consulting	Pa.		10, 21, 31, 38, 42, 70	8.0–12.0	5–	35–50	I.E. Degree
467	Aircraft	Ohio		54, 71	7.0–12.0	3–		
468	Air Cond. Mfg.	Tex.		80	Open	2–	25–35	
469	Air Cond. Mfg.	Tex.		81	Open	2–	25–35	
470	Mining & Smelt	N.M.		11, 13, 26, 36, 42, 45	Open		–45	I.E. Degree Preferred
471	Plastic Prod.	Va.		10	7.5–10.0	4–6	–37	MTM Experience
472	Plastic Prod.	Va.		10	6.0– 6.5	1–2	–30	MTM Experience
473	Electronics	Iowa		37, 50				M.S. of Ph.D.
474	Food Processing	Ill.		13, 15, 16, 22, 36, 38	5.8– 7.8	0–5	26–35	I.E. or M.E. Degree
475	Printing	N.Y.		11, 42, 44, 46	– 8.5	2–5		
476	Metalworking	Ohio		13, 15, 36, 37	7.0–	2–5	25–30	
477	Metalworking	Ohio		53		2–5	25–30	
478	Cotton Mfg.	N.H.		10, 26, 28, 37, 70	–11.0			Textile Experience
479	Brass Products	Conn.		10, 20, 36		1–5		Math. Experience
480	Navy	Fla.		10, 34, 52				Degree
481	Non-Ferrous Metals	Conn.		11	8.0– 9.0	5–10	30–40	
482	Dairy	Mass.		10, 40, 81	7.0– 8.0	5–7	33–38	I.E. Degree
483	Chemical	Tenn.		10, 30, 53	5.5–	1–5	22–30	I.E. Degree Preferred
484	Oil Seal	Ohio		11, 20, 31, 36, 42, 61, 93		5–		I.E. Degree
485	Electronics	N.Y.		10, 36, 42	– 9.5	5–		B.S.M.E./I.E.
486	Printing & Publishing	Calif.		19, 31, 36	10.0–15.0		30–40	MBA Desirable
487	Electronics	Tex.		11, 16, 30, 32, 36	6.0–8.5	1–5	24–35	I.E. Degree
488	Gen. Construction	Tex.		50, 70	6.6–8.4	5–	–30	

Key to Job Classifications

No.	Job Classification
10	Motion and Time Study
11	Methods Improvement
12	Suggestion Systems
13	Work Measurement and Perf. Stds.
14	Stop Watch Time Study
15	Std. Time Data Dev. & Applic.
16	Predeter. Elemental Time Stds.
18	Work Sampling
19	Estimating and Costing
20	Wage Payment
21	Incentive Plans
22	For Production Workers
23	For Non-Prod. Workers
24	For Supervisory Personnel
26	Job Evaluation
28	Wage Administration
30	Production Engineering
31	Production Control
32	Process Planning and Routing
33	Scheduling and Loading
34	Flow Process Charting
35	Inventory Control
36	Cost Anal. & Reduction
37	Statistical Quality Control
38	Budgetary Control, Standard Costs
39	Tool and Gage Design and Control
40	Plant Engineering
41	Plant Location & Expansion
42	Plant Layout
43	Material Handling
44	Machinery & Equipment
45	Specif., Select. & Eval.
46	Replacement
47	Automation
48	Plant Maintenance
49	Cap. Budget. Facil. Plan
50	Operations Research
51	System & Simulation with "Models"
52	Mathematical Analysis
53	Engr. Economy Studies
54	Auto. Data Proc. with Computers
55	Market Research & Forecasting
60	Industrial Relations
61	Personnel Administration
62	Personnel Testing
63	Personnel Training
64	Industrial Psychology
65	Labor Relations
66	Safety Engineering
67	Suggestion Systems
70	Systems and Procedures
71	Admin. & Operating Procedures
72	Organization Charts and Manuals
73	Records Admin. & Form Control
80	Product Design
81	Packaging
90	Management and Supervision
91	Industrial Engineering Supr.
92	Chief I. E. or Equiv.
93	Plant Engineer
94	Production Supervisor
95	Plant Mgr., Fact. Mgr., Works Mgr.
96	General Manager

American Institute of Industrial Engineers, Inc.
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Columbus 15, Ohio

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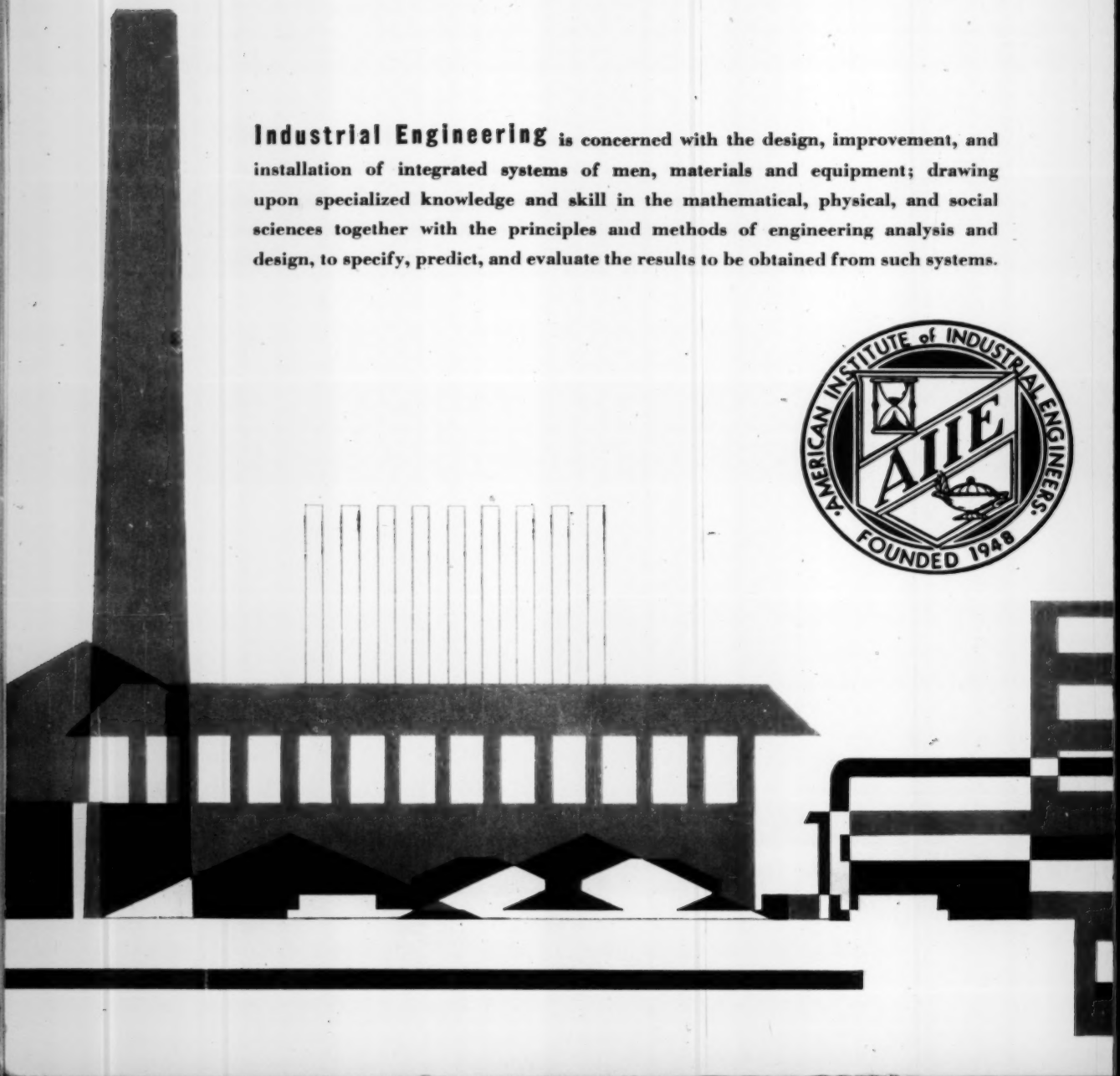
Industrial Engineering is concerned with the design, improvement, and installation of integrated systems of men, materials and equipment; drawing upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design, to specify, predict, and evaluate the results to be obtained from such systems.